Fishery Data Series No. 09-50

2006 Northern Southeast Inside Sablefish Stock Assessment and 2007 Forecast and Quota

by

Sherri C. Dressel

October 2009

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	\$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

The Alaska Department of Fish and Game (ADF&G) manages the sablefish fishery in the Northern Southeast Inside (NSEI, "Chatham Strait") management area of Southeast Alaska with a harvest rate approach, wherein a harvest rate is applied to an estimate of biomass to determine the acceptable biological catch (ABC). Mortalities from bycatch in other fisheries are deducted from the ABC to determine the annual harvest objective (AHO). Other indicators of population size and health, such as fishery and survey catch per unit effort, age composition, and information from Gulf of Alaska, Bering Sea, Aleutian Islands, and Canada west coast sablefish populations, are also considered when determining the AHO.

The abundance of sablefish in the NSEI management area is estimated using mark-recapture methods. Based on Chapman's modification of the Petersen estimator, there were an estimated 2,427,828 sablefish in the NSEI management area at the time of the 2006 fishery. The forecast for 2007 was 2,203,396 sablefish or 16,750,915 pounds of sablefish. An $F_{40\%}$ (= 0.116) harvest rate was applied to the 90% lower confidence limit of the forecasted biomass to yield an ABC of 1,623,219 pounds for the 2007 NSEI sablefish fishery. The ABC was decremented by 135,000 pounds to account for estimated mortality in the halibut fishery and other sources of fishery mortality. The resulting value was rounded to the nearest thousand pounds to yield a final AHO of 1,488,000 pounds for the 2007 NSEI sablefish fishery. A compressed age composition, lack of strong recruitment, and constant or decreasing catch-per-unit-of-effort indices all support managing the NSEI sablefish fishery conservatively.

Preliminary results of a contract investigation to evaluate current ADF&G stock assessment methods for NSEI sablefish and to explore alternatives are presented in the Appendices.

Key words: Sablefish, black cod, *Anoplopoma fimbria*, longline, pot, Chatham Strait, Northern Southeast Inside, NSEI, mark-recapture, southeast Alaska

INTRODUCTION

Sablefish, *Anoplopoma fimbria*, have been commercially harvested in the Northern Southeast Inside (NSEI) management area (commonly known as "Chatham Strait fishery") of the Southeast District of the Gulf of Alaska (GOA) since the early 1900s, with the first recorded catches occurring in 1906 (Bergmann 1975). The Chatham sablefish fishery is the oldest and most lucrative groundfish fishery managed by the State of Alaska (Richardson and O'Connell 2003). The Chatham sablefish fishery is an equal quota share (EQS) fishery and the size of the EQS is determined annually, based on the annual harvest objective (AHO). The size of the NSEI sablefish population is estimated annually using mark-recapture methods. The AHO is calculated by applying an $F_{40\%}$ harvest rate to the lower 90% confidence limit of the forecasted biomass and subtracting the estimated mortality in the halibut fishery and other sources of mortality.

Sablefish in the eastern North Pacific range from the Bering Sea slope, Aleutian Islands, and GOA, down the Pacific coast to central Baja California (Allen and Smith 1988). Dramatic differences in Von Bertalanffy growth parameters and age at maturity provide evidence that sablefish throughout this range constitute 2 stocks: one north of 50° north latitude, and one south (Kimura et al. 1993; 1998). Also, tag-recovery data provide evidence that sablefish comprise 2 stocks with a low exchange rate across the 50° north latitude boundary. Minimal migration on the short term justifies the separation of these stocks for management purposes. However, the exchange rate between the stocks, albeit low, is probably sufficient to consider sablefish a single biological population throughout its range, as long as sablefish in the north and south are not reproductively isolated (Kimura et al. 1998).

There is considerable mixing of sablefish throughout the range of the northern stock (Kimura et al. 1998), hereafter referred to as Alaska sablefish. Based on tag studies, the migratory behavior of sablefish in the Southern Southeast Inside (SSEI) management area and NSEI appear to differ. Alaska Department of Fish and Game (ADF&G) tagged sablefish in Behm Canal (within SSEI) from 1979 to 1981. Results from the SSEI tagging study provide evidence of net outward movement of young fish from coastal fjords to offshore areas resulting in migration between management areas (Bracken 1983). However, a tagging study in the eastern GOA, including Chatham and Clarence Straits (1983–1991) provides evidence that a large portion of the Chatham Strait population (NSEI) may be non-migratory (Maloney and Heifetz 1997). In that study, 89% of the tags released in Chatham Strait were recovered in Chatham Strait, whereas only 58% of the tags released in Clarence Strait were recovered in Clarence Strait. The study did not account for different fishing and reporting rates, which may have led to underestimates of migratory fish (Maloney and Heifetz 1997).

To avoid the potential complications arising from migration, the NSEI sablefish stock assessment method of mark-recapture is one that only requires an assumption of closure over a short time period (June to November). For statistical analyses, the NSEI population is assumed to be closed during these 5 months and mark-recapture studies are used as the basis of stock assessment. While some violation of this assumption is unavoidable, migration is expected to be low enough to avoid large bias in mark-recapture estimates. In addition to the mark-recapture results, fishery catch per unit effort (CPUE), longline survey CPUE, age composition, weight at age, biomass and recruitment trends in the GOA, Bering Sea, and Aleutian Islands areas (managed by National Oceanic and Atmospheric Administration Fisheries, NOAA) and Pacific waters of Canada (managed by the Department of Fisheries and Oceans, DFO) are also considered when setting annual harvest quotas.

Due to questions regarding the performance of the mark-recapture and variance estimator for the Chatham Strait sablefish stock, a contract was issued to Dr. Franz Mueter of Sigma Plus in January, 2007, to evaluate current stock assessment methods and to explore alternatives. Numerous stock assessment methods were considered including several more detailed mark-recapture models, a time-series model, and age-structured-assessment (ASA) models. The mark-recapture models were explored to assess the effects to the variance when a number of variable factors were included. The 2007 quota was based upon the same mark-recapture assessment methods used since 2003 because the full results of the Sigma Plus contract were not available. Those contract results completed at the time the quota was set are presented in Appendices A–C. Although the results of the Sigma Plus contract were not used quantitatively to forecast biomass and set the commercial quota for Chatham Strait in 2007, the initial conclusions were reviewed and considered in the decision making process. This report presents the stock assessment and data examined as the basis for setting the 2007 quota.

STUDY SITE

The Chatham Strait sablefish longline fishery is conducted in the NSEI Subdistrict of the Southeast District of the GOA (Figure 1). Although NSEI includes other waters, the fishery is conducted almost entirely in Chatham Strait, a deepwater fjord, with a small amount of harvest coming from Frederick Sound. Sablefish are a deepwater species, generally inhabiting depths greater than 200 fathoms. For this reason, most of the sablefish harvest is from the deep waters of Chatham Strait, rather than in the shallower waters within the remainder of NSEI. Fishing locations in Chatham Strait extend from the southernmost tip of Coronation Island in the south to the northernmost of Lincoln Island in the north (Figure 1). The relative removals from the fishery follow a similar pattern year to year, with the most harvest from the center of Chatham Strait in statistical areas 345701 and 345631 (Figure 2).

METHODS

SURVEY SAMPLING AND ANCILLARY DATA

Pot Survey

An annual ADF&G pot survey (hereafter referred to as "pot survey") is conducted in June to catch, mark, and release sablefish in the NSEI management area. O'Connell and Holum (2007) describe the methods and results of the 2006 pot survey. During the 2006 pot survey, healthy sablefish greater than 55 cm fork length were tagged with a t-bar tag and marked by removing the distal third of the dorsal lobe of their caudal fin (clipped) and subsequently released (Figure 3). Healthy sablefish from 51 cm to 55 cm were clipped, but not tagged, and released. Sablefish less than 51 cm were measured and released. As a rule, sablefish smaller than 51 cm were released without marks because of the high probability that, if caught, they would be discarded from the fishery, due to the relatively low market value of such small fish. If fish less than 51 cm were included in the initial sample size of marked and released fish and significant numbers of these small fish were caught during the commercial fishery recovery phase, but discarded, and not accounted for in the estimation process, the abundance estimator could be biased.

The goal of the survey was to distribute marked sablefish among statistical areas in Chatham Strait and Frederick Sound (Figure 2), approximately in proportion to population abundance in those areas. Because sablefish abundance by statistical area was not known, marked fish were distributed in proportion to the commercial harvest of sablefish from those statistical areas in 2005, which was assumed to be proportional to population abundance. To help achieve sufficient mixing of marked and unmarked fish between the release and recovery events, there was particular effort to spread out releases of marked fish within statistical areas in addition to across statistical areas. Whereas in previous years, additional pots were set at locations where catch rates were high in order to most efficiently release marked fish, in 2006 second sets were forgone to spread out release of marked fish within the statistical area. This increased the spatial distribution of mark releases, while reducing the number of marked fish released.

Port Sampling and Logbooks

Data and information from the commercial fishery are important for assessing the NSEI sablefish population. Samples of commercial fishery harvest, data collected from fishery logbooks, and personal communications with fleet members were integral parts of the abundance estimation process. Fishery data were used in the design of pot and longline surveys. The geographic distribution of harvest and distribution of harvest by depth from logbooks was used to approximate the distribution of the population at large. This distribution was originally used to set the area sampled in the longline survey, and has been employed annually as a proportionate guide for distributing marked fish from the pot survey. The recovery of marked fish in the commercial harvest is the second stage of the mark-recapture estimation study. The locations of recovered tags were plotted versus the locations of their release from the pot survey to evaluate movement of sablefish within NSEI and migration out of NSEI management area. Personal communications with fleet members regarding the distribution, seasonal movements, and behavior of NSEI sablefish aided evaluation of the appropriateness of the abundance estimator for the Chatham population and provided ideas for how to achieve a better fit of the stock assessment process to NSEI sablefish.

For the recovery phase of the mark-recapture study, sablefish from the NSEI commercial longline fishery were examined for tail clips and the numbers of clipped and unclipped fish were recorded from each landing. Tags were collected at port and were associated with trip and set when possible. Trip clip counts that were questionable due to new observers, tally-wacker malfunctions, catches being mixed with federal sablefish individual fishing quota (IFQ) landings by the processor, and non-conducive observing conditions (fish moving too fast to observe) were excluded from the analysis.

Random biological samples were taken from most landings. The goal was to sample one out of every 83 fish, for a total of approximately 1,750 sampled fish (the estimated number necessary to result in at least 550 male and 550 female samples, based on the sex ratio from 2005 landings). Fish were sampled for length, weight, otoliths (age), sex and sexual maturity.

Fishery CPUE information was collected through a mandatory logbook program. CPUE is affected by hook spacing, but can be standardized with the asymptotic function developed by Skud and Hamley (1978). The International Pacific Halibut Commission (Sullivan et al. 1999) has standardized halibut CPUE using this method, and NOAA has adapted it for sablefish using hook spacing experiments conducted in Chatham Strait and GOA (Sigler and Lunsford 2001). For NSEI fishery CPUE, the number of standardized hooks (n_s) was computed from the number of unstandardized hooks (n_u) for each commercial longline trip and statistical area combination using the function adapted by Sigler and Lunsford (2001):

$$n_s = 2.2 \cdot n_u \left(1 - e^{(-0.57 \cdot h)}\right) \tag{1}$$

where n_s = the number of standardized hooks;

n_u = the number of unstandardized hooks (the actual number of hooks fished); and,

h = the hook spacing (meters).

The overall standardized fishery CPUE was calculated for the year by dividing the total biomass harvested in 2006 by the standardized number of hooks, summed across all trips:

$$CPUE_{std} = \frac{\sum harvest}{\sum n_s} \tag{2}$$

where $CPUE_{std}$ = the overall standardized fishery CPUE; and,

harvest = the number round pounds of sablefish caught by the commercial fishery.

No adjustments were made for differences in bait use or hook size. Trips specified in logbooks as targeting halibut were excluded from the calculation of overall fishery CPUE. All sablefish-target trips were included in the calculation of overall fishery CPUE, even if they contained individual sets that targeted halibut. Individual sets that targeted halibut on sablefish trips were only included if at least one sablefish was caught.

Longline Survey

In 2006, ADF&G awarded short-term (14-day) charter agreements to three commercial longline vessels to fish 14 or 15 stations each during the same time period in early August. The survey area was split into three distinct areas, one for each vessel, allowing all stations to be fished within a single 7-day period. The ADF&G longline survey (hereafter referred to as "longline survey") was comprised of 44 stations, with 25 skates and 45 hooks per skate set at each station (Figure 4). A skate was considered invalid if greater than 25% of the skate was missing, in a snarl, or stripped of hooks at the time of retrieval. Data from invalid skates were not used in the calculation of CPUE.

During retrieval of a skate, as each hook broke the surface its status was noted. A hook without a fish was recorded as "bare," "bait," or "invalid" (bent, broken, missing, or snarled). Fish that broke the surface attached to a hook were identified and recorded by species or species grouping. Sablefish that broke the surface on a hook but which were not landed were recorded as "lost." Sablefish determined visually to be less than approximately 45 cm (18 inches) were recorded as "small" and immediately returned to the water, unless they were scheduled to be a biological sample. Sablefish that were not marketable were recorded as "discarded", with discard reason reported if known.

After discarding invalid skates, a CPUE of sablefish per hook (fish per hook) for an individual station was calculated, by dividing the number of valid sablefish (includes the lost and released sablefish but not those caught on invalid skates) by the total number of hooks retrieved at that station.

$$cpue_i = \frac{f_i}{h_i} \tag{3}$$

where $cpue_i$ = the catch per unit of effort for station i;

f_i = the total number of sablefish caught at station i on valid subsets; and,

h_i = the total number of hooks fished at station i on valid subsets.

The overall fish per hook for the survey was calculated by dividing the total valid sablefish captured by the total hooks retrieved from valid subsets.

$$CPUE = \frac{\sum_i f_i}{\sum_i h_i} \tag{4}$$

where $CPUE$ = the overall catch per unit of effort (fish per hook) for all stations.

A CPUE of kilograms per hook for an individual station was calculated by multiplying the fish per hook for a station by the mean weight in kilograms from the fish sampled on that station.

$$cpue_{i:wt} = cpue_i \cdot w_i \tag{5}$$

where $cpue_{i:wt}$ = the catch per unit of effort for station i in kilograms per hook;

$cpue_i$ = the catch per unit of effort for station i in fish per hook; and,

w_i = the mean weight of sablefish sampled at station i in kilograms.

The kilogram per hook for the survey was calculated by multiplying the overall fish per hook by the overall mean kilogram for sampled sablefish.

$$CPUE_{wt} = CPUE \cdot W \tag{6}$$

where $CPUE_{wt}$ = the overall catch per unit of effort (kilograms per hook) for all stations;

$CPUE$ = the overall catch per unit of effort (fish per hook) for all stations; and,

W = the mean weight of sablefish sampled at all stations in kilograms.

An ADF&G crewmember was present on deck during the retrieval of the longline gear and collected biological samples. The first and every 10th fish thereafter on the first 13 skates at each station were sampled for biological data, with a goal of 550 biological samples for the survey. Biological data included length, weight, sex, sexual maturity stage, and otoliths. The fish following each biological sample was measured for length only, with a goal of 550 length-only samples for the survey. Otoliths were cleaned and sent to the ADF&G Age Determination Unit for break-and-burn age determination. The ADF&G crew cleaned and dressed the fish to industry standards and the vessel crew iced the sampled fish.

STOCK ASSESSMENT AND QUOTA CALCULATIONS

The 2006 stock assessment and 2007 quota calculations for NSEI sablefish were based on mark-recapture methods. The pot survey was used for the marking phase in June 2006 and the recapture phase was based on port sampling of commercial fishery landings from August to November, 2006. Abundance of NSEI sablefish at the time of the fishery was estimated after the fishery was complete. Population biomass at the time of the 2006 fishery was computed from abundance using age composition and weight-at-age data from the August 2006 longline survey. Forecasted biomass of NSEI sablefish for 2007 was estimated using the current-year (2006) estimates of population abundance, longline survey age composition, longline survey mean weight at age, the number of age-4 recruits, and a fixed natural mortality of 10% (as done in the Alaska federal sablefish assessment (Hanselman et al. 2006)). The acceptable biological catch (ABC) for 2007 was calculated by applying an $F_{40\%}$ harvest rate to the lower 90% confidence limit of the forecasted biomass. The annual harvest objective (AHO) for 2007 was calculated by subtracting the estimated mortality in the halibut fishery and other sources of mortality from the ABC.

2006 Estimates

The abundance of NSEI sablefish at the time of the 2006 fishery was estimated with mark-recapture methods and calculated using Chapman's modification of the Petersen estimator (Chapman 1951), as was done in 2001, 2003, 2004, and 2005. Chapman's modification of the Petersen estimator is calculated as,

$$N_t = \frac{(n_1 + 1)(n_2 + 1)}{m_2 + 1} - 1 \tag{7}$$

where N_t = estimated sablefish abundance at time *t;*

t = the year 2006;

n_1 = the number of marked fish released;

n_2 = the number of fish captured during the second sample (commercial fish that were examined for marks); and,

m_2 = the number of examined fish that had marks.

Given that the 2006 abundance of sablefish in NSEI met the requirement that N_t was greater than 150, and n_1 and n_2 were greater than 50, I estimated 90% confidence limits for the abundance estimate by finding the 2 largest roots of the cubic equation (i.e. solving for N_t^{CL}, where the low root becomes N_t^{LCL} and the upper root becomes N_t^{UCL})(Seber 1982 after Chapman 1948):

$$\frac{\left(m_2 - \frac{n_1 n_2}{N_t^{CL}}\right)^2}{n_2 \cdot \frac{n_1}{N_t^{CL}}\left(1 - \frac{n_1}{N_t^{CL}}\right)\left(\frac{N_t^{CL} - n_2}{N_t^{CL} - 1}\right)} = 1.645^2 \tag{8}$$

The biomass, B_t, of sablefish at the time of the 2006 fishery was estimated as:

$$B_t = \frac{1}{2}\sum_{s=1}^{2}\sum_{a=a_r}^{a_{\max}} N_t p_{a,t} \overline{w}_{a,s,t} \tag{9}$$

where s = sex (1 is male, 2 is female);

a = age;

a_r = age of recruitment (age-4);

a_{max} = maximum age observed in the longline survey in year *t;*

N_t = Petersen estimated number of fish in year *t;*

$p_{a,t}$ = proportion of sablefish at age *a* from the longline survey in year *t; and,*

$\overline{w}_{a,s,t}$ = mean weight at age, by sex, from the longline survey in year *t*.

2007 Forecast

Sablefish abundance (number of fish), N_{t+1}, forecasted for 2007, was calculated as,

$$N_{t+1} = N_t p_{a_r,t} + \sum_{a=a_r}^{a_{\max}} N_t p_{a,t} \zeta \tag{10}$$

where $p_{a_r,t}$ = proportion of sablefish at the age of recruitment (age-4) from the longline survey in year t ; and,

ζ = annual survival (90%).

The lower 90% confidence limit of sablefish abundance forecasted for 2007 was calculated as,

$$N_{t+1}^{LCL} = N_t^{LCL} p_{a_r,t} + \sum_{a=a_r}^{a_{\max}} N_t^{LCL} p_{a,t} \zeta \tag{11}$$

where N_t^{LCL} = lower confidence limit of the Petersen estimated number of fish at time *t.*

Note that the variability incorporated into the forecasted lower confidence limit of abundance for time *t+1* included only the variability in the estimate at time *t*, and not any variability in the forecasting process. Therefore, the forecasted lower confidence limit is likely an underestimate of the variability (i.e. confidence interval may be too narrow) in the abundance estimator for time *t+1*.

Biomass was forecasted for 2007 as,

$$B_{t+1} = \frac{1}{2}\sum_{s=1}^{2} N_t p_{a_r,t} \overline{w}_{a_r,s,t} + \frac{1}{2}\sum_{s=1}^{2}\sum_{a=a_r}^{a_{\max}} N_t p_{a,t} \overline{w}_{a,s,t} \zeta \tag{12}$$

where $\overline{w}_{a_r,s,t}$ = mean weight at the age of recruitment, a_r, by sex, from the longline survey in year *t.*

2007 Acceptable Biological Catch (ABC)

The ABC for 2007 was calculated as,

$$ABC_{t+1} = \frac{1}{2}\sum_{s=1}^{2}\overline{w}_{a_r,s,t}N_{a_r,t+1}^{LCL}\left(\frac{F_{40\%}}{M+F_{40\%}}\right)\left(1-e^{-M-F_{40\%}}\right)+$$

$$\frac{1}{2}\sum_{s=1}^{2}\sum_{a=a_r+1}^{a_{\max}+1}\overline{w}_{a,s,t}N_{a,t+1}^{LCL}\left(\frac{F_{40\%}}{M+F_{40\%}}\right)\left(1-e^{-M-F_{40\%}}\right) \tag{13}$$

where $N_{a_r,t+1}^{LCL}$ = lower confidence limit of the Petersen estimated number of fish at the age of recruitment (age-4) at time *t+1*;

$N_{a,t+1}^{LCL}$ = lower confidence limit of the Petersen estimated number of fish at age *a* and time *t+1*;

$F_{40\%}$ = the rate of fishing mortality that results in a spawning stock biomass per recruit that is 40% of that with no fishing; and,

M = natural mortality (10%).

For forecasting purposes, the lower confidence limit of the Petersen estimated number of fish at the age of recruitment (age-4) in 2007 was assumed to equal the lower confidence limit estimated for 2006,

$$N_{a_r,t+1}^{LCL} = N_{a_r,t}^{LCL} \tag{14}$$

where, $N_{a_r,t}^{LCL}$ = lower confidence limit of the Petersen estimated number of fish at the age of recruitment (age-4) at time *t*.

The Petersen estimated number of fish at the age of recruitment (age-4) in 2006 was calculated as,

$$N_{a_r,t}^{LCL} = N_{t}^{LCL}p_{a_r,t} \tag{15}$$

The lower confidence limit of the Petersen estimated number of fish at any age greater than that of age-4 in 2007 was calculated as,

$$N_{a_r+i,t+1}^{LCL} = N_{a_r+i-1,t}^{LCL}\zeta \quad \text{where } i = 1, 2, 3, \ldots (a_{\max} - a_r + 1) \tag{16}$$

where $N^{LCL}_{a_r+i,t+1}$ = lower confidence limit of the Petersen estimated number of fish at age a_r+i at time $t+1$, where i can take any value between 1 and $(a_{max} - a_r + 1)$; and,

$N^{LCL}_{a_r+i-1,t}$ = lower confidence limit of the Petersen estimated number of fish at age a_r+i-1 at time t, where i can take any value between 1 and $(a_{max} - a_r + 1)$

The lower 90% confidence limit of the forecast, which was used to set the ABC, was limited to the error in the Petersen estimate of number of sablefish. Because there are other sources of error that are not accounted for, the confidence interval around the forecast likely underestimates the total amount of error associated with forecasting abundance.

The estimate of $F_{40\%}$ used for the 2007 ABC was calculated using length at age (von Bertalanffy growth model), weight at length, and maturity at length from 2002–2006 longline survey random biological samples, 10% natural mortality, and gear selectivity parameters used by NOAA for their 2007 forecast (Hanselman et al. 2006) adjusted for the difference between ADF&G and NOAA aging. Selectivity can only be estimated with an age-structured model (NOAA uses, ADF&G does not), so NOAA's estimates have been used for calculating the ADF&G $F_{40\%}$ harvest rate. Adjusting NOAA's estimate of age at 50% selectivity (to approximate what it would have been had the aging been done by ADF&G) was expected to have reduced potential bias resulting from differences in aging between ADF&G and NOAA. NOAA and ADF&G aging results were compared in a recent study, the Committee of Age Reading Experts (CARE) Structure Exchanges[1], where aging experts from west coast agencies aged the same set of otoliths. Linear regression was used to compare the ages reported by NOAA (Alaska Fisheries Science Center) and ADF&G, and to adjust NOAA-estimated age at 50% selectivity to approximate results had the aging been done by ADF&G.

2007 Annual Harvest Objective (AHO)

The final AHO or quota, was calculated by reducing the ABC to account for estimated bycatch mortality in the halibut fishery and other fisheries and then rounding to the nearest thousand pounds. The biomass harvested during the longline survey (test fishery) was not subtracted off the ABC when calculating the 2007 AHO. The decrement for bycatch mortality was calculated by first estimating the pounds of Pacific halibut landed in NSEI from fishing grounds greater than 99 fathoms in depth. The pounds of sablefish caught in Chatham Strait during the Pacific halibut fishery outside of the 2007 NSEI Chatham Strait sablefish season were calculated based on the average ratio of sablefish to halibut pounds caught in these areas during the 2003, 2004, and 2006 International Halibut Commission surveys (information was not available for 2005). Sablefish mortality was estimated by assuming that 25% of the sablefish that were caught in the Pacific halibut fishery during this time died. In addition, other fishing related mortalities of sablefish are estimated to constitute approximately 3% of the ABC. Deducting these expected mortalities from the ABC and rounding to the nearest thousand pounds resulted in the AHO for 2007.

STOCK ASSESSMENT EVALUATION

In addition to completing the 2006 stock assessment, ADF&G contracted with a consultant (Dr. Franz Mueter) in 2007, to evaluate ADF&G stock assessment methods and recommend and develop advancements to the current methods. One goal of the contract was to evaluate the

[1] http://care.psmfc.org/index.php Date accessed: 28 July, 2009

appropriateness of the current mark-recapture point and variance estimators for NSEI sablefish. The consultant implemented a variety of mark-recapture models to evaluate their relative fits and explored how their variability differed from the frequentist "base" model currently used for NSEI sablefish stock assessment. As the Bayesian base model, the consultant implemented Chapman's modification of the Petersen estimator in a Bayesian framework. After establishing that the Bayesian point estimate and 90% credibility intervals were comparable to the frequentist point estimate and 90% confidence intervals used by ADF&G, he compared the Bayesian base model with additional models that were also implemented in a Bayesian framework. For the results of this work that were complete at the time the 2007 quota was set, see Appendices A through C. For all results of the contract, see "Evaluation of stock assessment and modeling options to assess sablefish population levels and status in the Northern Southeast Inside (NSEI) management area" (Mueter *in prep*).

RESULTS

SURVEY SAMPLING AND ANCILLARY DATA

Pot Survey

From 1 June through 25 June, 2006, 7,261 sablefish were captured in sablefish pots deployed from the F/V Ocean Cape (Table 1, Figure 5). Of the fish captured, 5,325 healthy fish greater than 55 cm in length were tagged with a t-bar tag, fin-clipped, and released. In addition, 749 fish from 51 cm to 55 cm were clipped, but not tagged, and released. Of the 7,261 fish caught and measured for length, 249 were released without being marked because they were less than 51 cm fork length.

Of the initial 6,074 marked sablefish released, 37 marked fish were captured and removed from the marked population prior to or during the NSEI commercial sablefish fishing season, but not by the NSEI sablefish fishery (only 35 of these were known and accounted for at the time of the mark-recapture assessment; Table 2). Of these 37 fish, 29 were known to have been captured and removed from the marked population prior to the commercial sablefish fishery recapture phase (26 fish from the annual longline survey, 2 caught by commercial fishermen outside NSEI, and 1 caught by commercial fishermen inside NSEI). An additional 8 were assumed to be unavailable to the NSEI commercial sablefish fleet (recovery phase), including one that was caught during the season as personal use harvest, one that was caught during the season by a halibut fisherman, and 6 caught during the NSEI sablefish season but outside NSEI.

Port Sampling and Logbooks

During port sampling (17 August–14 November, 2006), 204,462 sablefish from the NSEI commercial longline fishery were examined for tail clips. The final Petersen estimate was based on 89.8% of the total observations or 183,694 fish (n_2 in the calculation). Of that number, 456 sablefish (m_2 in the calculation) were identified with tail clips received during the 2006 pot survey (Table 2).

Tags collected from logbooks and during port sampling were used to evaluate sablefish movement between the times of tagging and recovery. For discussion of movement results see Assumptions of Mark-Recapture: Closure section in this document.

Fishery CPUE for 2006 was 0.092 fish per standardized hook. For a comparison of 2006 fishery CPUE with previous years, see Mark-Recapture, Longline Survey CPUE, and Fishery CPUE trends section in this document.

Longline Survey

A total of 25 skates and 1,125 hooks were set at each of 44 stations (exception: the first station had 29 skates), for a total of 1,104 skates deployed during the survey (Figure 4). Out of the 44 stations and 1,104 skates set, 18 sets had a combined total of 37 skates that were classified as invalid and not included in the calculation of CPUE.

CPUE was calculated both in terms of fish per hook and weight per hook (lb and kg). The CPUE in terms of fish per hook varied across stations, from 0.13 to 0.51, with an overall CPUE of 0.31. The CPUE in terms of lb/hook varied from 0.89 (0.40 kg/hook), to 3.85 (1.75 kg/hook), with an overall lb/hook of 2.41 (1.09 kg/hook).

A total of 14,990 sablefish were caught during the survey. Of these, 14,682 were caught on valid skates and 14,190 sablefish were retained. The remaining sablefish were either lost at the roller (361), released because they were very small (27), or discarded due to sand flea predation (43), sleeper shark predation (57), or other reasons (4).

A total of 1,482 sablefish were measured for length. Those sablefish had a mean length of 68 cm (27 in). The length distribution ranged from 48 cm (19 in) to 101 cm (39 in). Females were generally larger than males, with a mean fork length of 70 cm (27 in), compared to the male mean fork length of 64 cm (25 in).

Of the 1,482 fish sampled for length, 752 were also sampled for weight, sex, stage of maturity, and otoliths. The female: male ratio was 57:43. Out of the 752 fish sampled for maturity, only 6 females and 5 males were immature. The longline survey age composition indicates that the age structure of the NSEI population just before the fishery's onset was relatively narrow, and was comprised predominantly of ages 7 to 17 (Figure 6).

Recruitment is generally expected to appear in the Chatham Strait longline survey as 4-, 5-, 6-, or 7-year olds. Sablefish from the 2000 year class should have appeared as 6-year olds in Chatham Strait in 2006. However, a strong age-6 cohort was not apparent in the 2006 longline survey age composition (Figure 6). In addition, the pulse of sablefish that entered the population in the early 1990s–and likely supported the fishery for several years–appears to have diminished. There has been a much narrower distribution of ages in the past 3 to 4 years, as well as a decline in the proportion of sablefish older than 15 years of age, when compared to preceding years.

A total of 105,830 round pounds of sablefish and 1,169 round pounds of rockfish were landed from the longline survey test fishery, for a value of $291,814. Thirty-one percent of the catch came from statistical area 345631, 26% came from 345701, 23% from 345731, and 20% from 345603 (Figure 2).

2006 Abundance Estimate

The 2006 sablefish abundance estimate was 2,427,828 fish, with an associated 90% confidence interval of 2,259,843–2,620,065 (Table 2, Figure 7). The product of the Petersen estimate of sablefish abundance, the 2006 longline survey age composition, and the estimated mean weights at age from the combined 2002–2006 longline surveys yielded an estimated exploitable biomass of 17,813,518 pounds, with a 90% confidence interval of 16,580,977–19,224,002 pounds (Figure 8).

This estimated biomass was a 25.9% increase from the 2005 biomass estimate (14,151,692 lbs) and a 9.4% decrease from the 2004 biomass estimate (19,672,246 pounds).

2007 FORECAST

The forecast for 2007 was 2,203,396 sablefish. The estimated number of age-4 recruits into the exploitable population in 2006 and forecasted number of age-4 recruits into the exploitable population for 2007 was 6,606 fish. Using the estimated mean weights at age of sablefish from the combined 2002–2006 longline surveys yielded a forecast of 16,750,915 round pounds of exploitable sablefish (Figure 8). The 2007 forecast (16,750,915 lbs) is a 6.0% decrease from the 2006 biomass estimate (Figure 8).

2007 HARVEST RATE

The 2007 estimate of $F_{40\%}$ was 0.116. This rate was based on 2002–2006 longline survey biological data, and the result from the 2006 CARE sablefish exchange. The estimated age at 50% maturity (the age class which is composed of 50% mature and 50% immature sablefish) for both females and males was age 7. The estimated length at 50% maturity was 63 cm for females and 59 cm for males. Based on the CARE exchange study, the age at 50% selectivity (the age class for which 50% of the individuals are vulnerable to the longline gear) was 4.4 years for NOAA. This was approximately comparable to 6 years for ADF&G (Figure 9).

The estimate of $F_{40\%}$ for 2007 (0.116) was similar to that calculated for 2006, and greater than that calculated for 2004. The estimate of $F_{40\%}$ (recommended for setting the 2006 ABC) was 0.112. This estimate was based on biological data from the 2002–2005 longline survey biological data and adjusted NOAA selectivity (using the same CARE exchange relationship as used for the 2007 ABC). The recommended 2006 ABC was not used to establish the 2006 fishery quota. Instead the 2005 ABC and AHO were rolled over and used for the 2006 fishery. Therefore, the estimate of $F_{40\%}$ (= 0.137) that was calculated and used for the 2004 and 2005 ABCs was also used for 2006. This estimate was based on the following data sets: length at age from 1988–2003; weight at length from 1999–2002; maturity from 1988–1997; and, estimates of selectivity at age from NOAA with no adjustment for aging differences between ADF&G and NOAA.

Due to changes in aging methods, the years of data ADF&G used to calculate the 2007 harvest rate changed (compared to 2004, 2005 and 2006). A change in otolith pattern interpretation began around 1999, and the current interpretation (aging) methods were consistent beginning in 2002. Because of this, 2002–2006 data were used to calculate the 2007 harvest rate. The 2004 harvest rate calculation used age data estimated with two different pattern interpretations (earlier and current), versus the 2007 harvest rate calculation, which uses only the current pattern interpretation. The earlier pattern interpretation is believed to have had a negative bias (i.e. fish were concluded to be younger than they really were); the current interpretation reduces this bias. Chatham sablefish are therefore likely maturing at an older age than previously thought, and a lower harvest rate is warranted to avoid overfishing.

For the 2004 quota, the applied harvest rate of $F_{40\%}$=0.137, was set inappropriately high. This resulted from calculating the harvest rate using data estimated with two different aging methods. This was unintentional as staff was not aware that changes in otolith pattern interpretation had occurred until after the fact. While the 2004 $F_{40\%}$ harvest rate was below NOAA's overfishing level and near NOAA's $F_{40\%}$ adjusted harvest rate, it was greater than NOAA's $F_{40\%}$ adjusted harvest rate and overfishing level in 2005 and 2006 (Figure 10). The harvest rate was not recalculated in 2005 due to ADF&G staff turnover. In 2006, management staff deferred stock assessment recommendations, and used the previous year's quota, which was based on the harvest rate calculated in 2004. The change in otolith pattern interpretation was discovered, and accounted for, when calculating the harvest rate for 2007. The harvest rate used during 2004 to 2006 is now considered to have been inappropriately high.

Despite the lower harvest rate applied in 2007, the ADF&G harvest rate was still above what NOAA estimated as the threshold for overfishing in 2007, and was well above NOAA's $F_{40\%}$ adjusted =0.088 in 2007 (Figure 10). In 2007, NOAA changed its harvest rate calculation to be based on female (rather than female and male) maturity resulting in a harvest rate that is now closer to the harvest rate recommended by DFO. DFO has done analyses that suggest that the sablefish stock in the waters of British Columbia will on average decline with harvest rates greater than 0.08 and will hold or build with harvest rates that are lower.[2]

Another way in which the 2007 harvest rate calculation differed from that of 2004 and 2005 was that, in 2007, selectivity at age was adjusted to reflect the differences between NOAA and ADF&G aging. A third difference is that the same years of data were used to determine length at age, weight at length, and maturity at length for the 2007 harvest rate, whereas the harvest rate used during 2004–2006 used different years of data to calculate length at age, weight at length and maturity at length. Using datasets that were not synchronized could have led to invalid comparisons if changes had occurred in the population during the different time periods when data was collected.

2007 ABC

I calculated an acceptable biological catch (ABC) for 2007 of 1,623,219 pounds of sablefish, by applying an $F_{40\%}$ (= 0.116) harvest rate to the lower 90% confidence limit of the forecasted 2007 abundance and converting it to biomass. The decrease in the ABC from that recommended in 2005 (which was also used in 2006) is due to three things: 1) a decrease in the estimated number of fish from 2004 to 2006 (Petersen estimates), 2) a decreased harvest rate ($F_{40\%}$ = 0.137 for the 2004–2006 ABCs; $F_{40\%}$ = 0.116 for the 2007 ABC), and 3) an application of the harvest rate to the forecast (done for the 2007 ABC), rather than the estimated previous season abundance (done for the 2004–2006 ABCs). When calculating the 2004 ABC, a spreadsheet error resulted in the application of the harvest rate to the previous season's (2003) abundance, rather than the forecasted (2004) abundance. This error was replicated for the 2005 ABC, and the 2005 ABC was rolled over as the ABC for 2006. Because the mark-recapture estimates of 2003 and 2004 abundance were greater than the 2004 and 2005 forecasts (Figure 11), the resultant 2004–2006 ABCs were greater than they should have been.

2007 AHO

The final quota (AHO) of 1,488,000 round pounds was calculated by reducing the ABC by 135,000 round pounds to account for bycatch mortality in the halibut fishery and other fisheries, and then rounding to the nearest thousand pounds. Assuming a 25% mortality rate for the sablefish that are caught in the Pacific halibut fishery during this time, an estimated 97,079 pounds of sablefish are removed via bycatch mortality. In addition, it is estimated that there would be approximately 38,000 pounds of other fishing related mortalities of sablefish (3% of

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[2] Kronlund, A.R., Fisheries and Oceans Canada, Science Branch, Pacific Region, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, British Columbia V9T6N7.

the ABC). Deducting these expected mortalities from the ABC and rounding to the nearest thousand pounds results in the AHO for 2007.

The 2007 AHO is a 28% decrease from the 2006 AHO (the AHO rolled over from 2005). Due to a decrease in the number of permit holders from 105 in 2006 to 103 in 2007, the 14,450 pound Equal Quota Share (EQS) for 2007 was a 26% decrease from the EQS in 2006. The 28% reduction in the AHO for 2007 is a result of two main factors: 1) a 15% decrease in the AHO due to the difference between the 2004 estimated population biomass and the 2007 biomass forecast; and, 2) a 13% decrease in the AHO due to updating and standardizing data for estimating the $F_{40\%}$ harvest rate from that used for the 2004, 2005, and 2006 (rolled over from 2005) AHOs.

MARK-RECAPTURE, LONGLINE SURVEY CPUE, AND FISHERY CPUE TRENDS

Selecting consecutive years of biomass estimates made with the same estimator (Petersen estimates) results in a time-series of 4 years of comparable estimates. Although the time series is short, the point estimates suggest a decreasing trend over time (Figure 8). However, uncertainty in the estimates is considered to be underestimated, due to the relatively simple estimator and the heavy reliance on assumptions. Therefore, the trend may not be statistically significant.

Survey CPUE (fish per hook) is currently at a moderate level in relation to the last twenty years (Figure 12). Survey CPUE has been relatively stable over the past 6 years with a moderate decrease from 2005 to 2006. The benefit to survey CPUE data is that, unlike fishery CPUE, the estimator is unbiased. The drawback is that survey CPUE data can be highly variable due to the relatively low sample size (compared to fishery CPUE). Survey CPUE is considered to be a useful index but less informative than the mark-recapture estimates.

Long-term patterns in the fishery suggest that CPUE is currently at low levels relative to the 1980s through mid-1990s, and generally increasing since 1998, but possibly decreasing since 2003 (Figure 13). Although the fishery CPUE benefits from large sample size, less weight should given to it when compared to trends in the mark-recapture estimates or survey CPUE, because of lack of standardization (of soak times, locations fished, target species, bait types, etc.) and the resulting possibility of biased trends in the index. In particular, commercial production may mask downward trends in population abundance. Despite concerns of harvesting at a rate that was too high during the last 3 years, there is no clear downward trend in fishery CPUE. However, sablefish are long-lived, so a decline may not be apparent before multiple years of overharvest.

Because there is migration of sablefish between Chatham Strait and the GOA and population trends in the two regions may be related, NOAA longline survey and longline fishery CPUE trends were also reviewed. Trends in the eastern GOA are also of interest because it is considered a part of the main spawning area (central and eastern GOA). NOAA East Yakutat/Southeast survey CPUE has decreased from 1991 through 2003, but was stable in 2004, increased in 2005, and remained stable for 2006 (Figure 14). Fishery CPUE in the East Yakutat/Southeast region followed a decreasing trend from 1995 to 2000/2001, then had a strong single-year increase in 2001/2002 and has remained approximately constant through 2005 (the last year reported; Figure 14).

ASSUMPTIONS OF MARK-RECAPTURE

Closure

Tag returns from different geographical areas were compared to address the assumption of closure of the population, specifically regarding possible emigration of tagged fish from the study area. Between the time of release (June pot survey) and the end of the 2006 fishing season (15 November), there were 541 tags recovered and returned from fish marked in June 2006 that had associated date and area of recovery information (Table 3). Of the tags returned, 98.5% (533 out of 541) were captured in the NSEI, which was similar to that of 2005 (96.7%), 2003 (99.3%), 2002 (98.2%), and 2001 (99.3%). Data from 2004 were not included in this comparison because fish were marked with Passive Integrated Transponder (PIT) tags and, therefore could not be observed outside of NSEI. The preponderance of returns from the NSEI in 2006, despite substantial fishing effort in areas outside the NSEI (e.g. federally managed IFQ sablefish fishery in the Southeast Regulatory Area of the GOA, commercial fishery in British Columbia), suggests that during the time between tagging in Chatham Strait (1 June–15 June) and the completion of the NSEI sablefish fishery in 2006 (15 November), relatively few sablefish moved from the NSEI into the GOA or to British Columbia. Assuming that tag-reporting rates from fisheries outside the NSEI fishery were at least roughly similar to those experienced in the NSEI fishery, emigration does not appear to have contributed to significant violation of the closure assumption.

While some mortality occurred over the approximately 5-month span of this study (i.e. from the initial tagging to the end of the fishery), the Petersen estimator (same methods as previous years) did not account for any mortality during this time (a fixed value of 10% annual natural mortality/emigration was assumed when forecasting). However, natural mortality was incorporated into modeling conducted as part of the contract (see Appendices A through C).

Equal Capture Probability

One of the crucial assumptions underlying the Petersen estimator is that the second phase (the recapture phase) is randomly sampled (Seber 1982). Because sampling in the recapture phase was from the commercial fishery landings and the commercial fishery does not sample randomly, this assumption does not hold for our study. However, in practice the Petersen estimator may be reasonable when the second sample appropriately reflects the population proportion of marked fish. This can occur if the following conditions are met: (1) there is uniform mixing of marked and unmarked fish so the proportion of marked fish is constant throughout the population; and (2) if all fish at a sample location, whether marked or unmarked, have the same probability of being caught.

Tag data indicates there is considerable movement of sablefish throughout Chatham Strait. Of the tags that were recovered in NSEI with statistical area specified, 37% (173 out of 472) were recovered in a different statistical area than from which they were released (Table 3). In addition to movement among statistical areas, there was considerable movement of fish within statistical areas (exact locations of recoveries not disclosed due to confidentiality). Movement within Chatham Strait supports the mark-recapture assumption of equal capture probability due to mixing, while the limited emigration suggests that the violation of the closure assumption is small.

The primary reason for using different gear types to capture (survey pots) and recover (commercial fishery longlines) sablefish is to try to reduce the chance of unequal capture probabilities of marked and unmarked sablefish. Trauma to sablefish, associated with the specific gear used for initial capture and marking, may cause sablefish to avoid that same type of gear ("gear shyness") during the recapture phase of the study. To the extent that marked sablefish might tend to avoid a particular gear because of prior trauma associated with the initial capture, marked fish could have a lower probability of recapture, compared to unmarked fish. Although use of different gears for the mark and recapture phases is intended to promote equal capture probabilities by avoiding gear shyness, it may actually promote un-equal capture probabilities if one or both of the gear types is size selective. As described in the Appendices, possible effects of selectivity on the Petersen mark-recapture estimates for Chatham Strait are still in the process of being quantified.

Equal Mortality Rates for Tagged and Untagged Fish

This implies that there are no inherent differences in mortality rates between tagged and untagged fish and that there is negligible or no tagging-related mortality. To the extent that there may have been tagging-related mortality, there would be fewer marked fish available for recapture, resulting in a biased, overestimate of abundance. As part of the contract, a model was constructed to investigate whether there are different mortality rates for tagged and untagged fish, but did not produce reasonable results (Appendix A), so differences in mortality rates are still unknown in NSEI.

All Fish in Recapture Phase Correctly Identified

The tail clips are fairly distinct marks, making marked and unmarked fish clearly discernable (Figure 3). However, some confusion can arise, and has arisen during previous mark-recapture surveys, when natural or fishing-related injuries occur to a sablefish tail that may appear similar to the clip used for marking. In addition, on occasion, some fish with clipped tails are overlooked or erroneously counted as unmarked. Because tail clips have been used to mark Chatham sablefish in previous years, port-sampling supervisors are familiar with the appearance of the tail clips. Other samplers are trained by the supervisors to be able to identify the tail clips and distinguish the clips from tail injuries. Trips for which supervisors question the identification of clips by new samplers are excluded from the analysis. For the trips that were included in the analysis, the number miscounted (counted as a clip if it was not or not counted as a clip when it was) was probably negligible and is probably an insignificant source of bias in the abundance estimates.

No Mark Loss

Because tail clipping was used as the marking method for use with the Petersen mark-recapture estimator, and because there were only approximately 5 months between the beginning of the marking and end of the recapture periods, there is very low probability that marks could have been "lost" due to re-growth of the clipped portion of the tails. Effective "loss" of the mark could have occurred if the tail clip was obscured by additional injury to the tail in the vicinity of the tail clip, or if the margin of the clip became frayed sufficiently to be judged a natural tail injury and not counted as a mark by observers in the fish processing plants. To the extent that any such losses might have occurred, they would tend to introduce a bias resulting in overestimate of abundance. Although such mark "losses" may have occurred, the number of such occurrences was probably negligible and likely to introduce little, if any, actual bias in abundance estimates.

DISCUSSION

Stock assessment recommendations and management decisions for Chatham Strait sablefish are made based on a consideration of a number of analyses and pieces of information. Quotas since 2003 have been based on a mark-recapture biomass forecast, an $F_{40\%}$ harvest rate that accounts for biological characteristics of the population, and decrements of mortality in the sablefish and other fisheries. These calculations are only used however, if they make sense when considering numerous other pieces of information, such as Chatham longline survey and longline fishery CPUEs, age composition, and the status of sablefish in the GOA, Bering Sea, Aleutian Islands, and waters of Canada. The harvest rate approach to management was developed for NSEI to manage by preventing population declines due to overfishing rather than taking corrective action after a precipitous drop in the abundance.

A decrease in the $F_{40\%}$ harvest rate between 2006 and 2007 is responsible for a 13% decrease in the AHO. I have greater confidence in the harvest rate calculated for 2007 than those calculated in 2004 to 2006, because the 2007 calculation used synchronized years of data, more precise age estimation, consistent age estimation techniques, and datasets that were adjusted for ADF&G aging if the otoliths were not read by ADF&G age readers. Retrospectively calculating harvest rates for 2004 through 2006 with these methods resulted in lower harvest rates than had been used in those years, suggesting that NSEI sablefish harvest rates in 2004 through 2006 were inappropriately high.

Even though the harvest rate used for the 2007 AHO ($F_{40\%}$=0.116) was a decrease over that used in 2004–2006 ($F_{40\%}$=0.137), it was still greater than that used by NOAA for the GOA, Bering Sea, and Aleutian Islands sablefish in 2007 ($F_{40\%}$ adjusted=0.088; Hanselman et al. 2006) and that recommended by DFO for sablefish in the northeastern GOA (*personal communication*, A. R. Kronlund). Given that sablefish from the Bering Sea south to northwest Vancouver Island are considered a single population (Kimura et al. 1998), harvest rates based on population parameters (length at age, weight at age, maturity at age, etc.) would be expected to be similar between NSEI and the GOA, though some differences by region could be possible. The NOAA harvest rate calculation for 2007 used female maturity, rather than combined female and male maturity, which partially explains the lower harvest rate when compared to NSEI.

For future years, consideration will be given to using a more conservative harvest rate strategy in NSEI. This could include using a calculation more closely aligned with the NOAA calculation, which uses female maturity only. It could also include using a calculation that accounts for bias in the population estimate as a result of differential selectivity by fishermen based on fish size (see Appendix A for more detail). Another option that will be considered is to decrease the harvest rate when spawning biomass approaches $B_{40\%}$ which is the approach used in NOAA's $F_{40\%}$ adjusted calculation.

A 15% decrease in the AHO is due to a decrease in estimated/forecasted biomass. The estimated biomass for 2006 and forecasted biomass for 2007 were both greater than the estimate for 2005, but less than the estimates for 2003 and 2004. Because the 2006 AHO was rolled over from 2005 (it was based on the 2004 biomass estimate), the AHO for 2007 was actually a decrease from the 2006 AHO. Having both the 2005 and 2006 biomass estimates less than that of 2004 gives additional support to the belief that population size may be decreasing and the decision to use the 2007 forecast as the basis for the 2007 AHO.

In addition to the mark-recapture abundance estimator, longline survey CPUE and longline fishery CPUE were studied when setting the 2007 AHO. The longline survey CPUE exhibits no trend over the last 6 years and is at an intermediate level in relation to the last 20 years. Fishery CPUE has increased from 1998 to 2003, but has decreased since 2003. Fishery CPUE is at a very low level in relation to the last 20 years. These fishery and survey CPUE trends support managing the NSEI stock conservatively.

The population age composition, as estimated from the longline survey, was also studied closely when setting the 2007 AHO. Recruitment is generally expected to appear in the Chatham Strait longline survey as 4-, 5-, 6-, or 7- year olds. There appears to be a lack of strong recruitment in NSEI over the last 5 or 6 years. The 2000 year class in the north Pacific was considered to be strong based on NOAA's observations and modeling of GOA, Bering Sea, and Aleutian Islands sablefish (Hanselman et al. 2006). Based on DFO observations, the 2000 year class was not as strong in British Columbia as in GOA/BSAI. In addition, DFO has observed low recruitment coast wide since the 2000 year class (*personal communication*, A. R. Kronlund). The 2000 and later year classes (age-6 fish and younger in 2006) do not appear strong in NSEI (Figure 6).

In addition to low recruitment, the pulse of sablefish that entered the population in the early 1990s and likely supported the fishery for several years appears to have diminished. As a result, in the past 3 to 4 years there has been a much narrower distribution of ages relative to preceding years and a decline in the proportion of older fish. Since older fish are generally larger and more fecund, compressing the age distribution around younger, smaller fish during a period of population decrease could reduce the reproductive potential of the population, further warranting conservative management of this stock.

Due to statistical uncertainty in estimating the harvest rate and the forecast to which it is applied, concerns about fishery selectivity biasing both estimates, and a recognition that test fish harvests are not deducted from the AHO, ADF&G has taken some steps to manage NSEI sablefish conservatively and is considering others. Using the lower 90% percent confidence limit of an abundance estimate as a basis for setting the ABC has been used for managing Chatham sablefish. This is one step ADF&G has taken toward conservative management. Using the lower confidence limit is consistent with approaches used in other state-managed fisheries (Hebert et al. 2002; O'Connell et al. 2002; Pritchett 2003). The lower confidence limit is used as a conservative step to account for uncertainties in the estimation of sablefish abundance. Because of the relatively large sample sizes used in both the marking and recapture phases, the 90% confidence interval around the point estimate of number of fish returning is quite narrow (approximately $\pm$6%). However, the 90% confidence interval used to set the ABC is misleading because it is limited only to error in the Petersen estimate of number of sablefish and, therefore, it is an underestimate of the total amount of error associated with forecasting abundance. So while using the 90% lower confidence limit of the forecast for setting the ABC is a conservative step, the effect is limited because the uncertainty in the abundance estimator is likely underestimated.

ADF&G is considering changing from an $F_{40\%}$ (less conservative) to a $F_{45\%}$ (more conservative) harvest rate in future years. In recent years, the NSEI AHO has been calculated by applying an $F_{40\%}$ harvest rate to the lower 90% confidence interval of Chatham sablefish forecasted abundance. NOAA uses an $F_{40\%}$ adjusted harvest rate, which currently results in a harvest rate between $F_{40\%}$ and $F_{45\%}$ for GOA, Bering Sea, and Aleutian Islands sablefish. Using an $F_{45\%}$ harvest rate is suggested by Field [3], for groundfish species. Use of an $F_{45\%}$ harvest rate would be a conservative measure to guard against possible overharvest, which could result because of misspecifying the harvest rate due to uncertainties in growth rate parameters and the influence of fishery selectivity on the estimated harvest rate and the estimated size of the population to which it is applied. ADF&G is continuing to use an $F_{40\%}$ harvest rate for the 2007 AHO and is considering an $F_{45\%}$ harvest rate for future years.

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The author acknowledges the assistance of many people for help with the research and reporting of this project. In particular, I would like to thank Franz Mueter (address: Franz Mueter, Sigma Plus, 1085 Arctic Circle, Juneau, Alaska 99801) who authored the analyses and summary contained in the appendices while under contract with the Alaska Department of Fish and Game. I would like to thank Cleo Brylinsky, Groundfish project leader and manager, for her leadership and support and Kyle Hebert, Marine Fisheries Supervisor, for supporting and administering the contract with Franz Mueter. I thank Mike Vaughn, Deidra Holum, Kamala Carroll, Jennifer Stahl, and Becky Knight for leading the fieldwork, data entry, mapping, and data summaries, and without whose help the stock assessment would not be possible. I acknowledge Dave Carlile, Tory O'Connell, and Barry Bracken for the initial implementation and refinement of the Southeast sablefish stock assessment program, upon which ADF&G has been building. A special thanks to Mike Vaughn, Jennifer Stahl, and Deidra Holum for report figures and tables, to Renate Riffe for editing consultation, and to Kyle Hebert, Cleo Brylinsky, and an anonymous reviewer for insightful comments that have substantially improved this report.

[3] Field, J.C. 2002. A review of the theory, application and potential ecological consequences of $F_{40\%}$ harvest policies in the Northeast Pacific. Prepared for the Alaska Oceans Network. 101pp.

REFERENCES CITED

Allen, M.J., and G.B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Department of Commerce, NOAA Technical Report NMFS 66, Seattle.

Bergmann, W. 1975. Southeastern region sablefish stock status report. Program Review Report, Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

Bracken, B. 1983. The history of the US sablefish fishery in the Gulf of Alaska, 1902–1982. Pages 41-47 [*in*] Proceedings of the International Sablefish Symposium, Alaska Sea Grant Report 83-8, Anchorage.

Chapman, D.G. 1948. A mathematical study of confidence limits of salmon populations calculated from sample tag ratios. International Pacific Salmon Fisheries Commission, Bulletin II, New Westminster, B.C.

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to zoological census. University of California Publications in Statistics 1:131–160.

Hanselman, D.H., Lunsford, C.R., Fujioka, J.T., and Rodgveller, C.J. 2006. Alaska sablefish assessment for 2007. [*in*] Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage.

Hebert, Kyle, M. Pritchett, R. Larson, T. Thynes, and J. Clark. 2002. Southeast Alaska sea cucumber stock assessment and management, part III: 1992, 1995, 1998 and 2001 Seasons. Alaska Department of Fish and Game. Division of Commercial Fisheries, Regional Information Report 1J01-30, Juneau.

Kimura, D.K., A.M. Shimada, and S.A. Lowe. 1993. Estimating von Bertalanffy growth parameters of sablefish *Anoplopoma fimbria* and Pacific cod *Gadus macrocephalus* using tag-recapture data. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fishery Bulletin 91:271–280, Seattle.

Kimura, D.K., A.M. Shimada, and F.R. Shaw. 1998. Stock structure and movement of tagged sablefish, *Anoplopoma fimbria*, in offshore northeast Pacific waters and the effects of El Niño-Southern Oscillation on migration and growth. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fishery Bulletin 96:462–481, Seattle.

Maloney, N.E., and J. Heifetz. 1997. Movements of tagged sablefish, *Anoplopoma fimbria*, released in the eastern Gulf of Alaska. Pages 115–121 [*in*] M.E. Wilkins and M.W. Saunders, editors. Biology and management of sablefish, *Anoplopoma fimbria*. U.S. Department of Commerce, NOAA Technical Report NMFS 130, Seattle.

Mueter, F. *In prep*. Evaluation of stock assessment and modeling options to assess sablefish population levels and status in the Northern Southeast Inside (NSEI) management area. Alaska Department of Fish and Game, Division of Commercial Fisheries, Special Publication, Douglas.

O'Connell, V., C. Brylinsky and D. Carlile. 2002. Demersal shelf rockfish stock assessment for 2003. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J02-44, Douglas.

O'Connell,V. and D. Holum. 2007. 2006 NSEI (Chatham Strait) tagging survey. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J07-04, Douglas.

Pritchett, M. 2003. Geoduck Clam Stock Assessment Surveys and Fishery Management for the 2002/2003 Season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J02-47, Douglas.

Richardson, B., and V. O'Connell. 2003. The Southeast Alaska Northern Southeast Inside sablefish fishery information report with outlook to the 2004 fishery. Division of Commercial Fisheries, Regional Information Report 1J04-03, Juneau.

Seber, G.A.F. 1982. The estimation of animal abundance. 2nd edition. MacMillan Publishing Co. New York.

Sigler, M.F. and C.R. Lunsford 2001. Effects of individual quotas on catching efficiency and spawning potential in the Alaska sablefish fishery. Canadian Journal of Fisheries and Aquatic Sciences 58:7, 1300–1312, Toronto.

REFERENCES CITED (Continued)

Skud, B.E., and Hamley, J.M. 1978. Factors affecting longline catch and effort: I. General review. II. Hook-spacing. III. Bait loss and competition. International Pacific Halibut Commission, Scientific Report No. 64, Seattle.

Sullivan, P.J., Parma, A.M., and Clark, W.G. 1999. The Pacific halibut stock assessment of 1997. International Pacific Halibut Commission, Scientific Report No. 79, Seattle.

TABLES

Table 1.–Fate of sablefish captured in pots on the Northern Southeast Inside (NSEI) sablefish pot survey, 1 June–15 June, 2006.

Fate of Sablefish	Number of Sablefish
Retained; other agency tag	1
Clipped only and released	749[a]
Clipped only, re-released	2
Discarded due to fleas	294
Discarded, not marketable	26
Discarded, too small	249
Released; already tagged by ADF&G	90
Released; already tagged by other agency	2
Retained; Bio. sample	523
Tagged and released	5,325
Grand Total	7,261

[a] A clipped-only sablefish that was caught on a subsequent pot and harvested as a biological sample is not included in this count.

Table 2.–Information used to calculate the Petersen population estimate for NSEI sablefish and the resultant estimates and 90% confidence limits for 2003 –2006. Information used for calculation includes the number of fish marked and released during the pot survey adjusted by the number of fish recaptured prior to or during the NSEI season but not by the NSEI fishery, the number of fish observed for marks during port sampling, and the number of recovered marked fish observed during port sampling.

Year	Adjusted Number Marked	Number Observed	Number of Recovered Marks	Population Estimate	Lower 90% Confidence Limit	Upper 90% Confidence Limit
2003	7,735	190,097	529	2,774,712	2,594,939	2,978,433
2004	6,312	219,924	518	2,675,118	2,501,350	2,872,325
2005	7,044	168,708	609	1,948,450	1,831,518	2,079,876
2006	6,039	183,694	456	2,427,828	2,259,843	2,620,065

Table 3.–Number of tagged fish that were released in the Northern Southeast Inside (NSEI) management area in June, 2006, that were subsequently recovered by 15 November, 2006 (the end of the NSEI commercial sablefish fishing season). Tags are listed by release statistical area, and by recovery management (mgt) authority, management area, and statistical area. Tags for which the recovery location was not known within a specific statistical area were grouped as a "not specified" recovery. Shading indicates the number of fish that were released and recovered in the same statistical area.

Statistical Areas in which Tags were Released		Number of Tag Recoveries, by Government Jurisdiction, Management Area, and Statistical Area														
		State of Alaska									United States Government				Canadian Government	
		NSEI									CSEO	SSEO				
		345803	345731	345701	345702	335701	345631	345603	355801	Not Specified	355601	345537	345500	Not specified	3D (04)	5B (06)
NSEI	345803	7	5	3	—	1	3	1	—	4	—	—	—	—	—	—
	345731	2	12	11	—	2	3	2	—	12	—	—	—	—	—	—
	345701	5	7	152	3	1	50	3	1	26	—	1	—	1	1	—
	345702	—	—	1	1	—	2	—	—	2	—	—	—	—	—	—
	335701	—	—	—	—	2	—	—	—	1	—	—	—	—	—	—
	345631	5	5	21	5	3	113	10	—	12	1	—	2	—	—	1
	345603	—	—	6	—	—	11	12	—	4	1	—	—	—	—	—

FIGURES

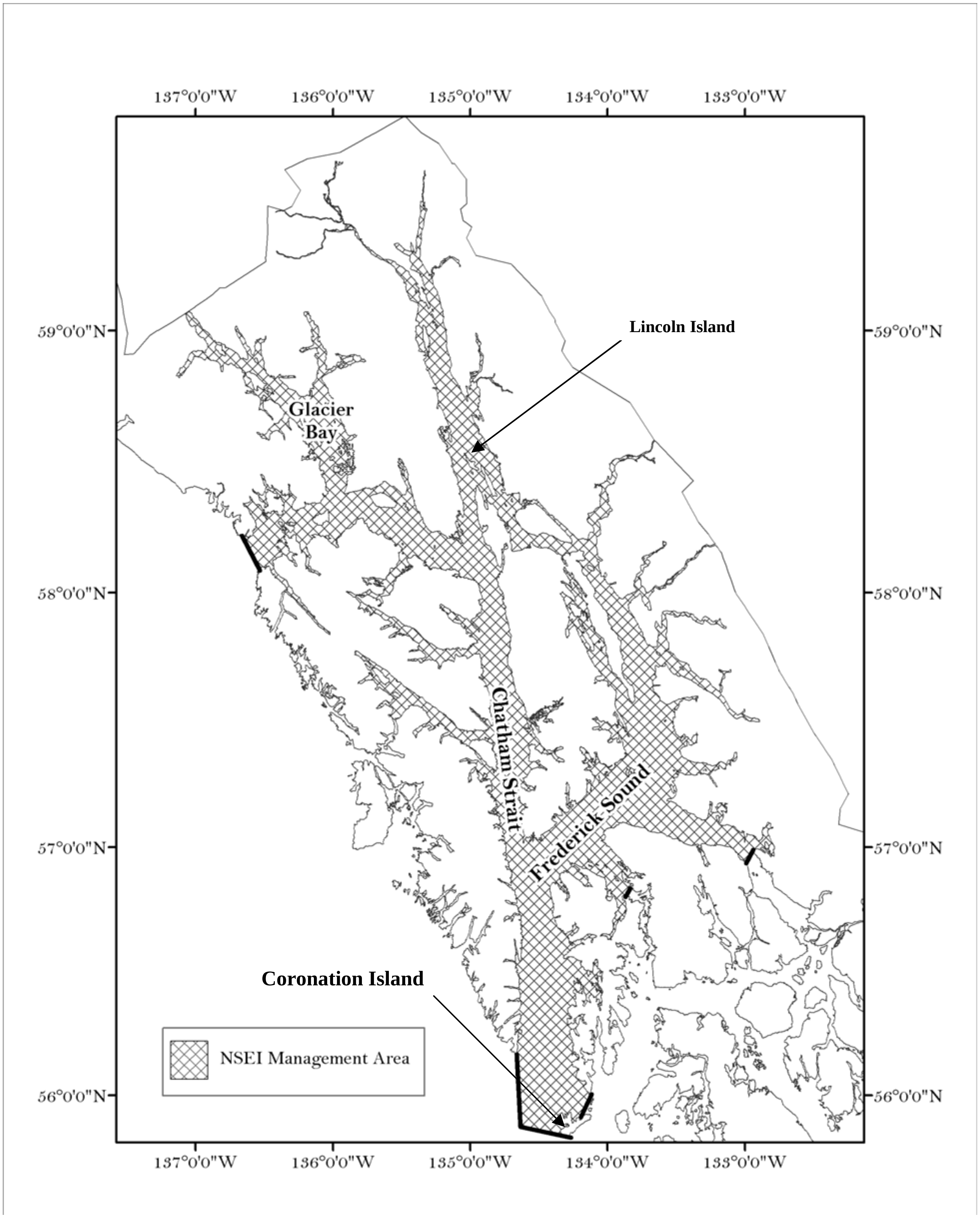

Figure 1.–Northern Southeast Inside (NSEI) management area (figure taken from Richardson and O'Connell (2003) with island identification added).

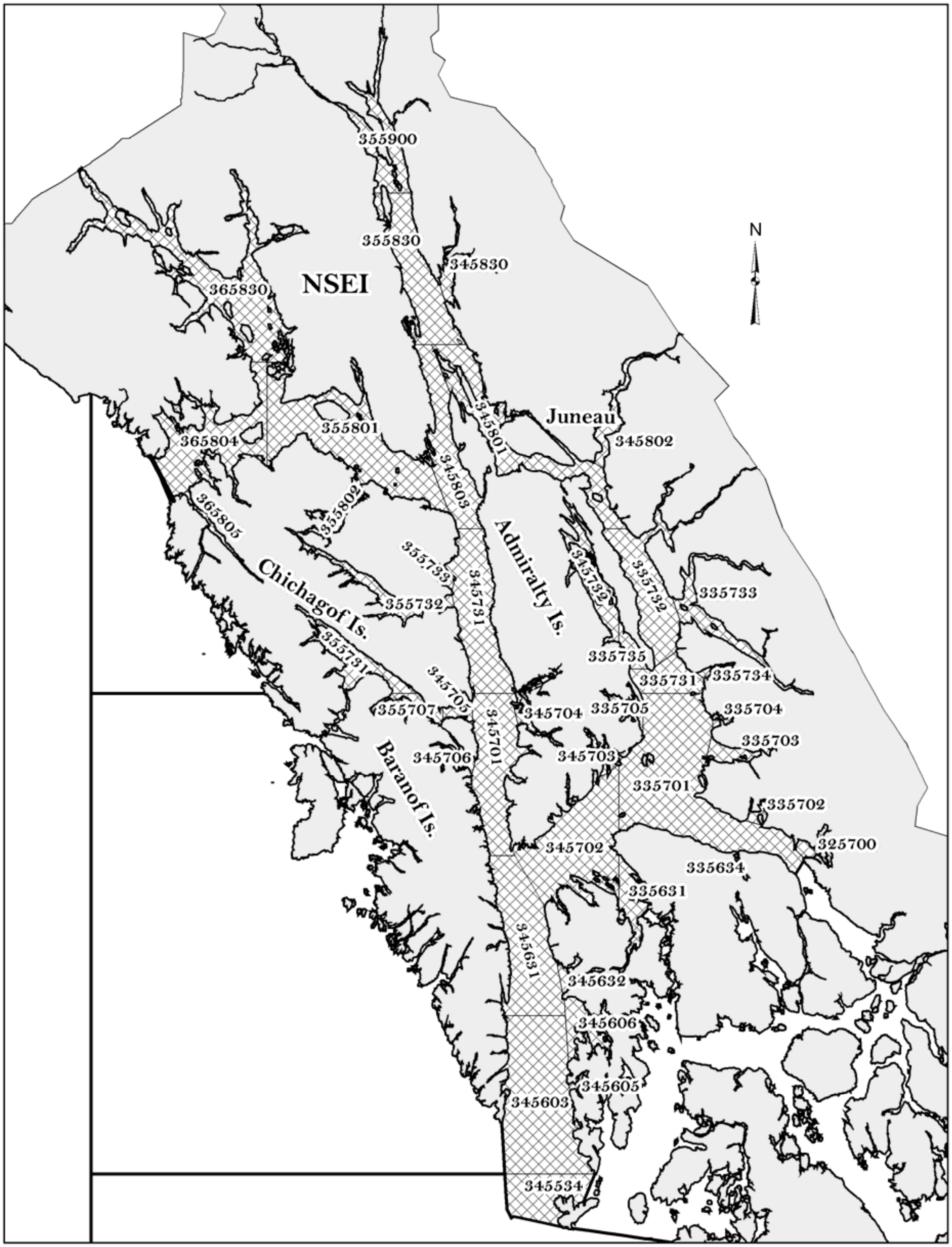

Figure 2.–Statistical areas within the Northern Southeast Inside management area (figure copied from Richardson and O'Connell 2003).

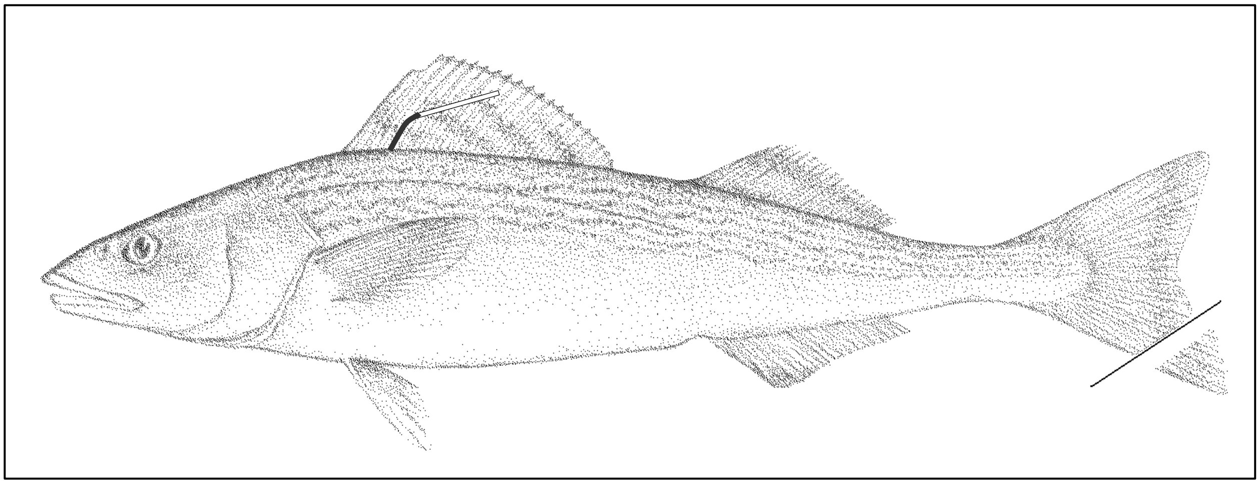

Figure 3.–Configuration and locations of marks on sablefish double-marked on the 2006 Northern Southeast Inside pot survey. Sablefish were "clipped" by cutting off the lower third of the ventral lobe of the caudal fin. Sablefish were "tagged" by inserting a T-bar tag at the base of the dorsal fin. Fish from 51 to 55 cm were clipped; fish greater than 55 cm were clipped and tagged.

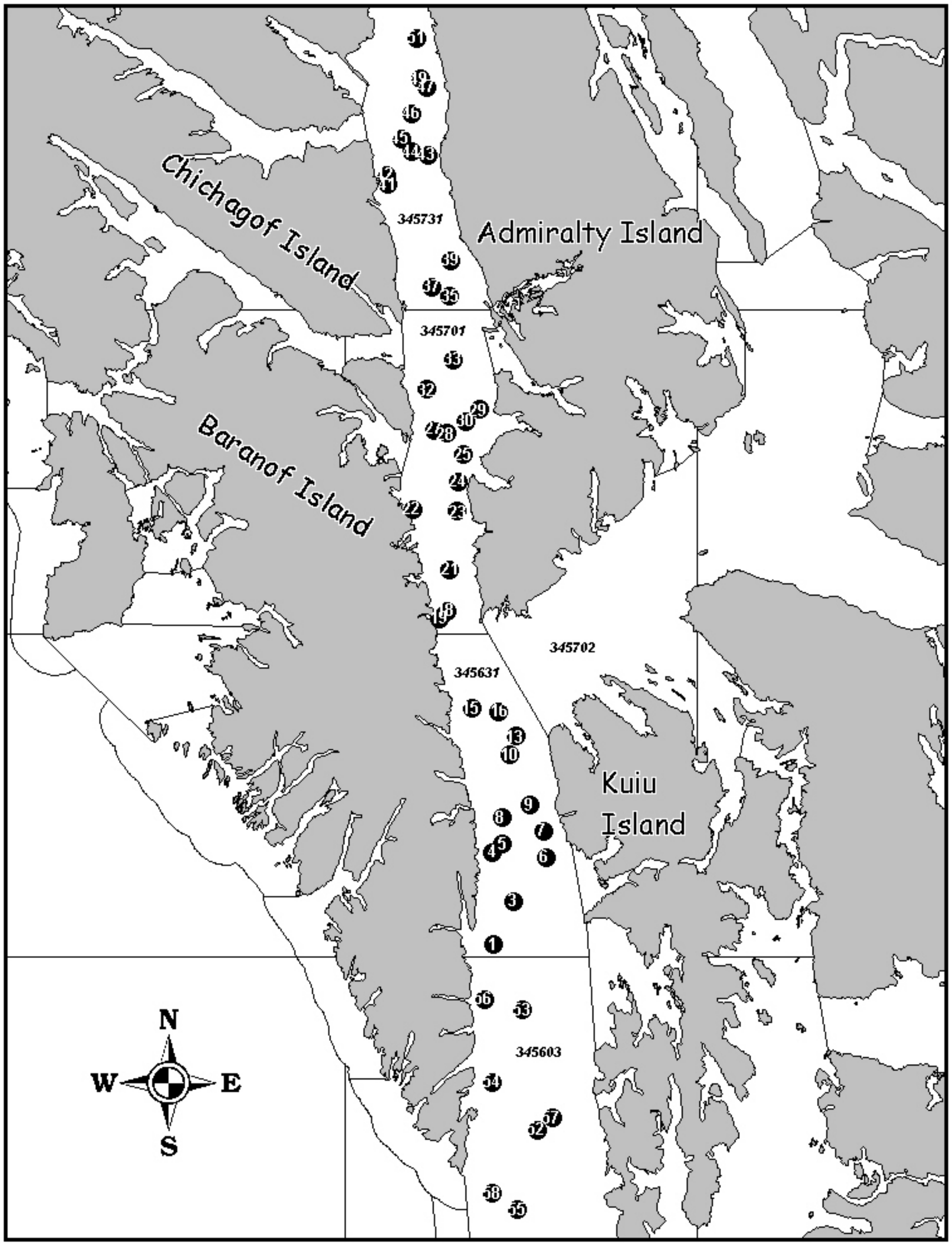

Figure 4.–Set locations by survey station, 2006 NSEI sablefish longline survey.

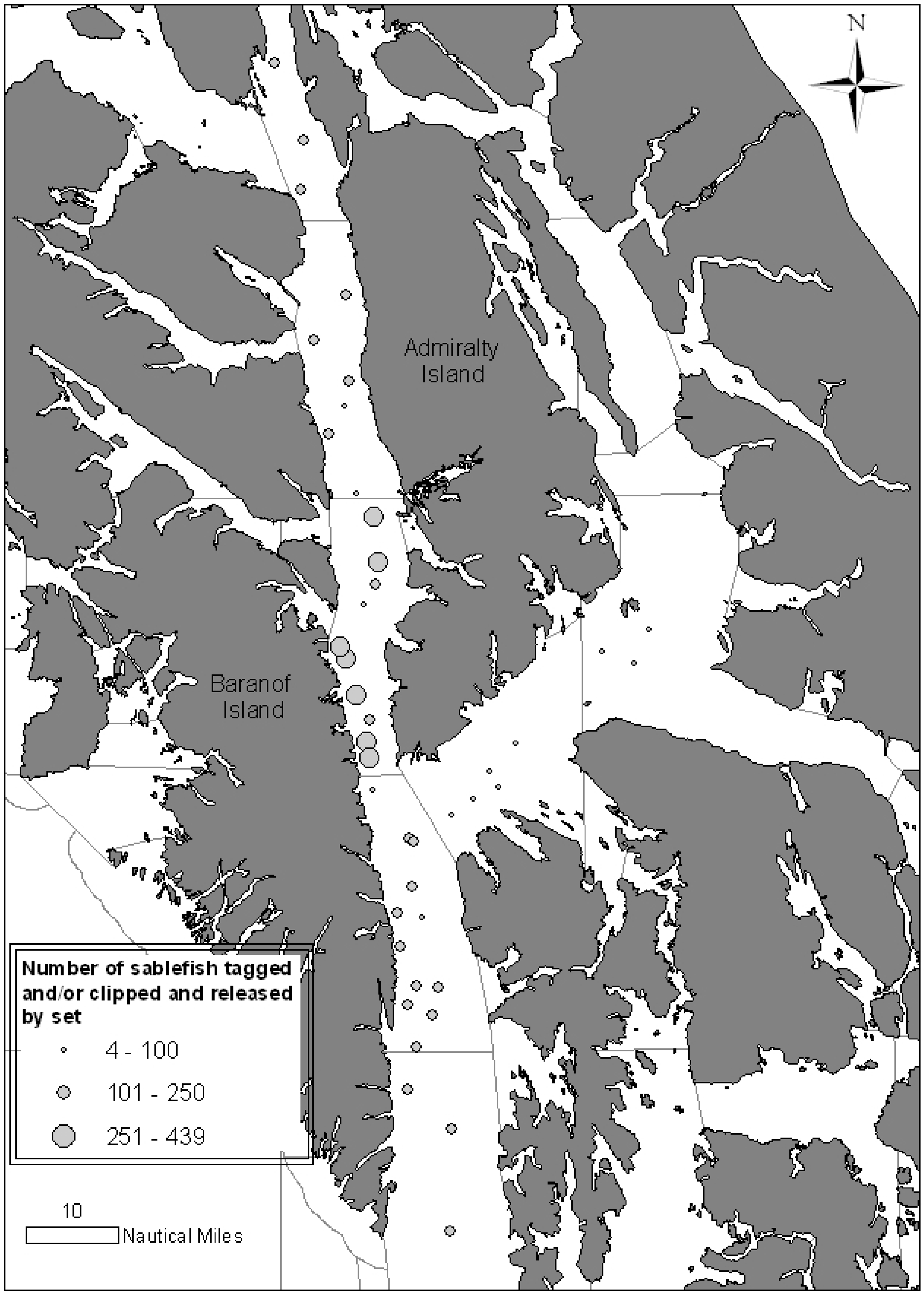

Figure 5.–Map displaying release locations of sablefish marked (tagged and/or clipped) during the 2006 pot survey (n=6,074). Size of dots indicates the number of tagged fish released per site (small=less than 100, medium=100–250, large=251–439).

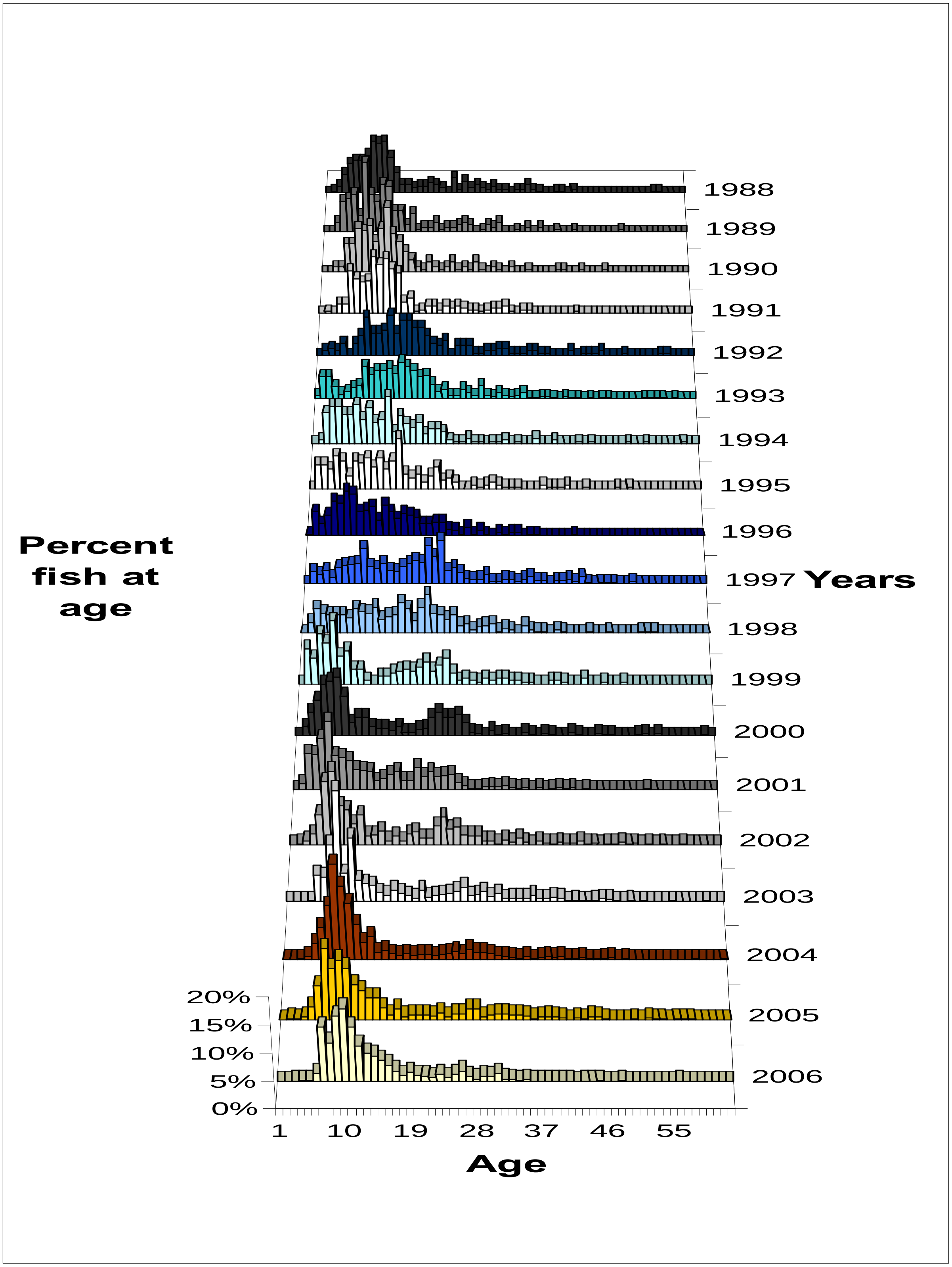

Figure 6.–Age composition of sablefish from the NSEI longline survey.

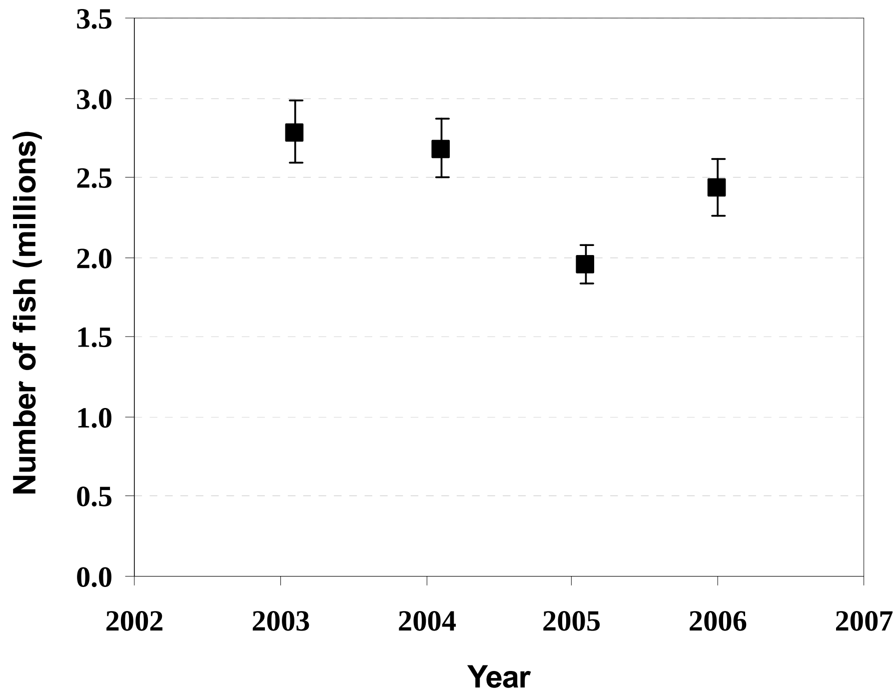

Figure 7.–Petersen mark-recapture estimates of NSEI population abundance for 2003 to 2006.

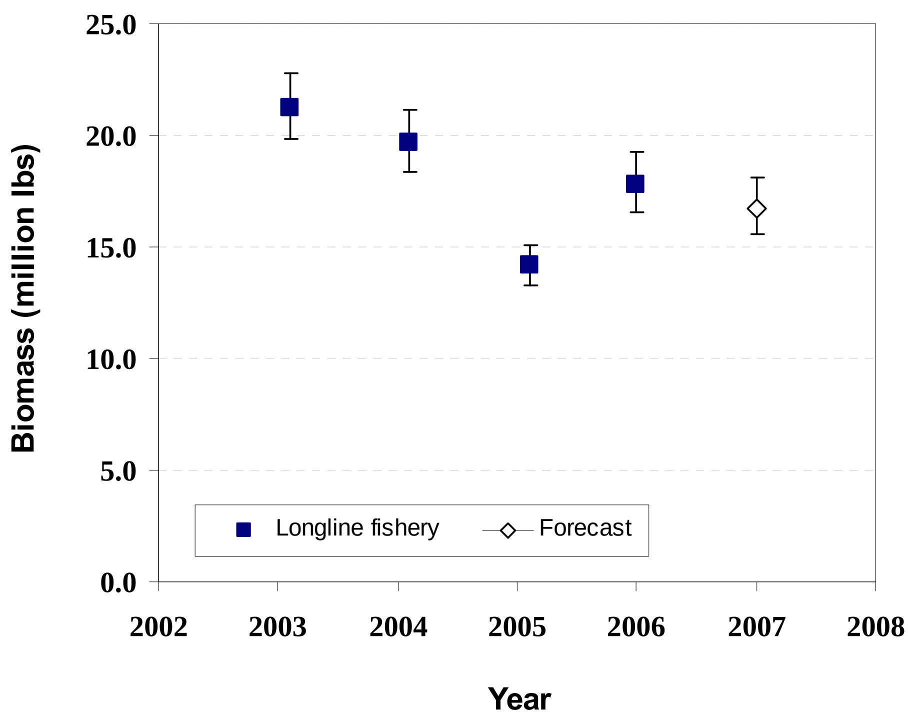

Figure 8.–Estimates of 2003–2006 exploitable biomass (squares), and 2007 forecast (diamond) with 90% confidence intervals.

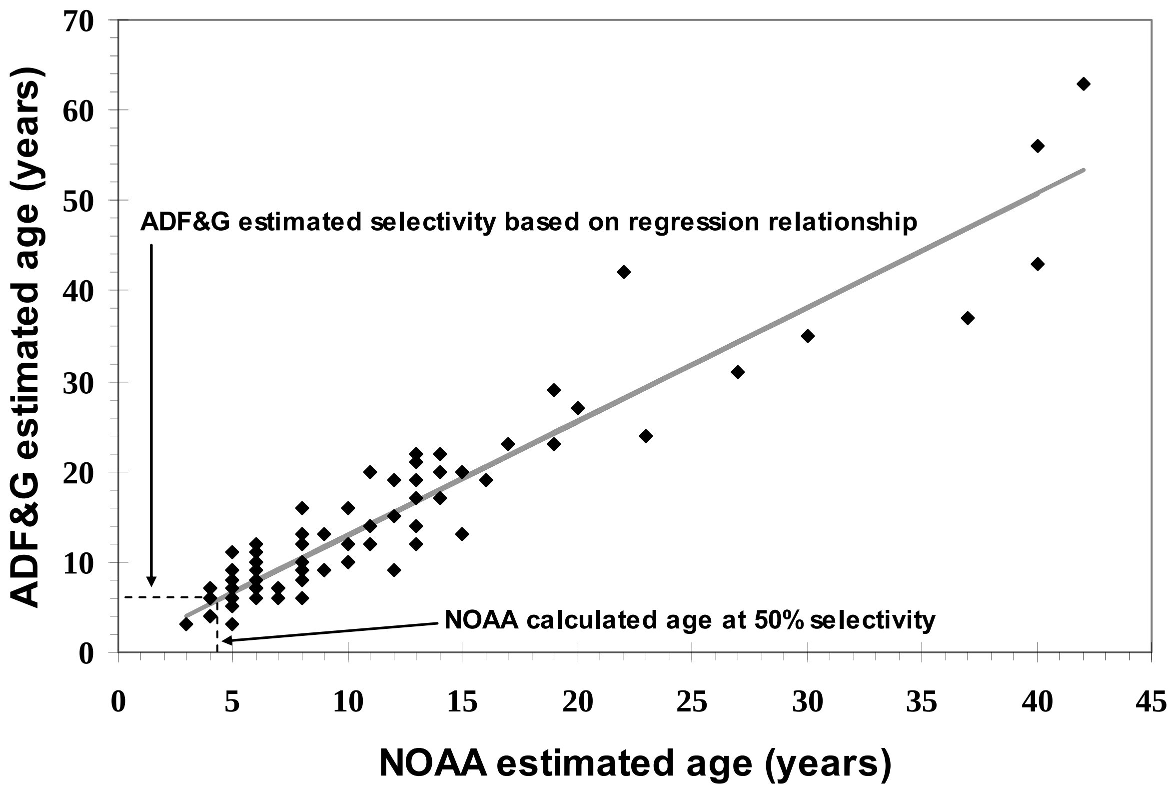

Figure 9.–Results of the 2006 Committee of Age Reading Experts (CARE) sablefish otolith exchange, with the age at 50% selectivity as calculated by National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, and corresponding estimated age for Alaska Department of Fish and Game noted.

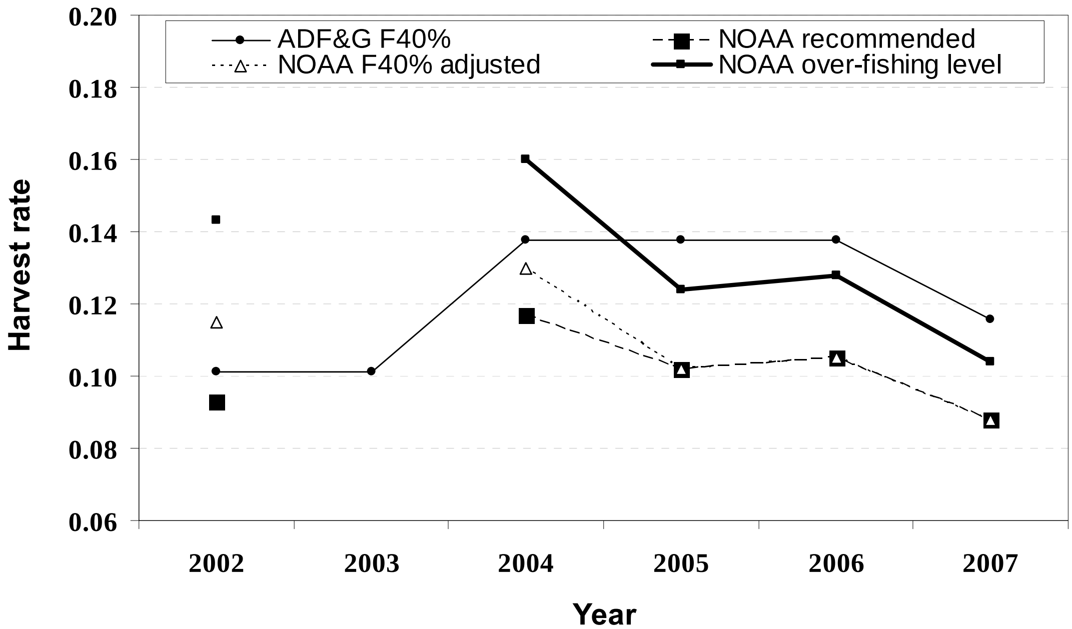

Figure 10.–Comparison of sablefish harvest rates among years and between agencies. ADF&G has used an $F_{40\%}$ harvest rate for calculating quotas. NOAA has recommended either an $F_{40\%}$ adjusted or more conservative harvest rate, depending on the year. NOAA's overfishing definition is equal to a $F_{35\%}$ adjusted harvest rate.

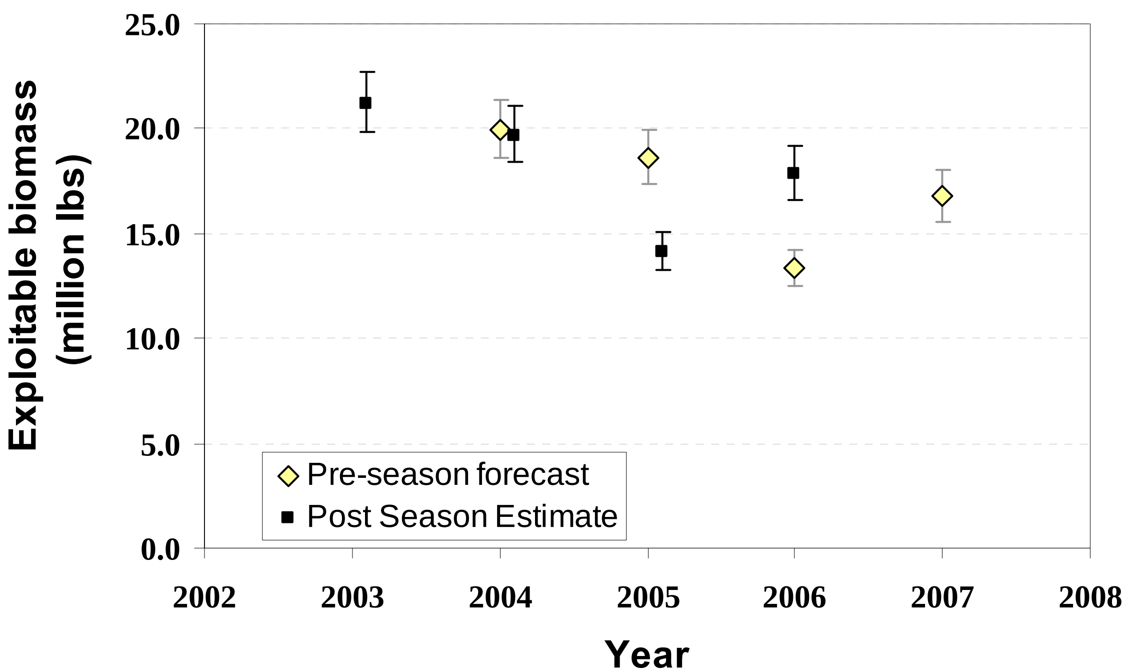

Figure 11.–Annual pre-season forecasts and post-season estimates of NSEI sablefish exploitable biomass, from 2003 to 2007.

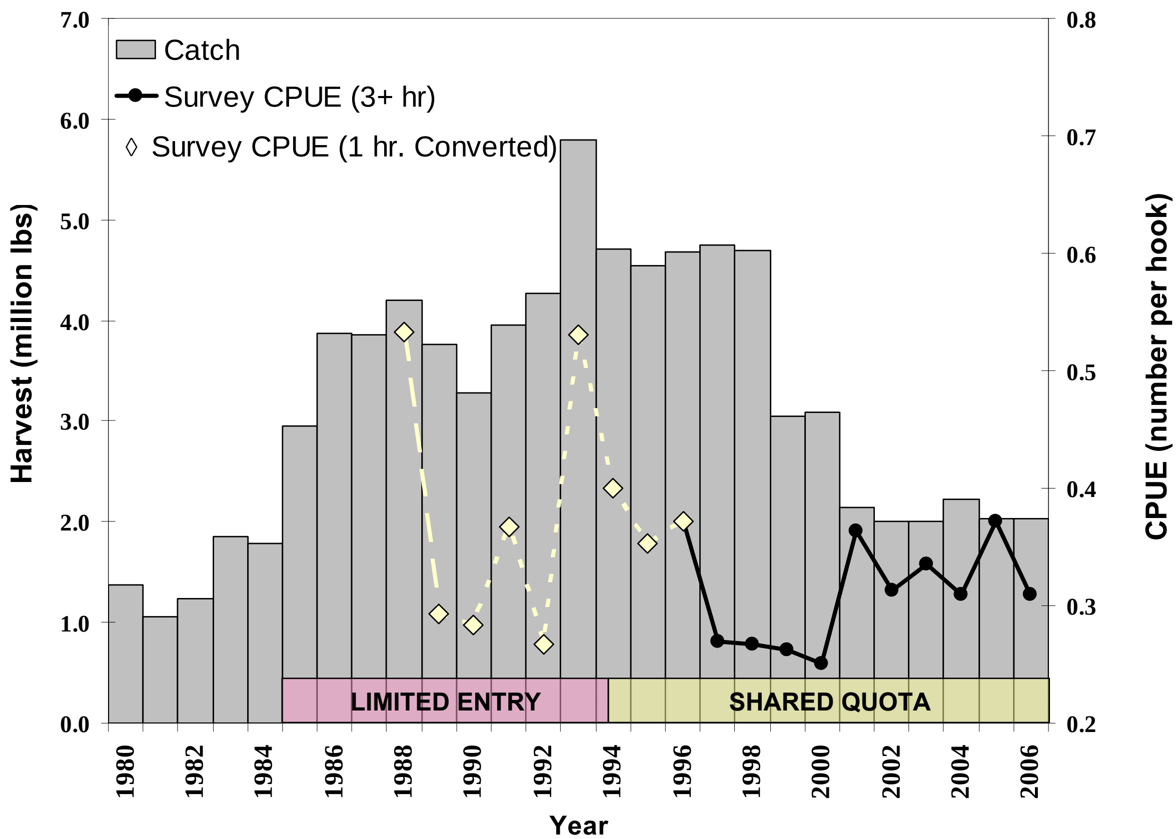

Figure 12.– NSEI sablefish long line survey catch per unit effort in fish per hook and harvest over time.

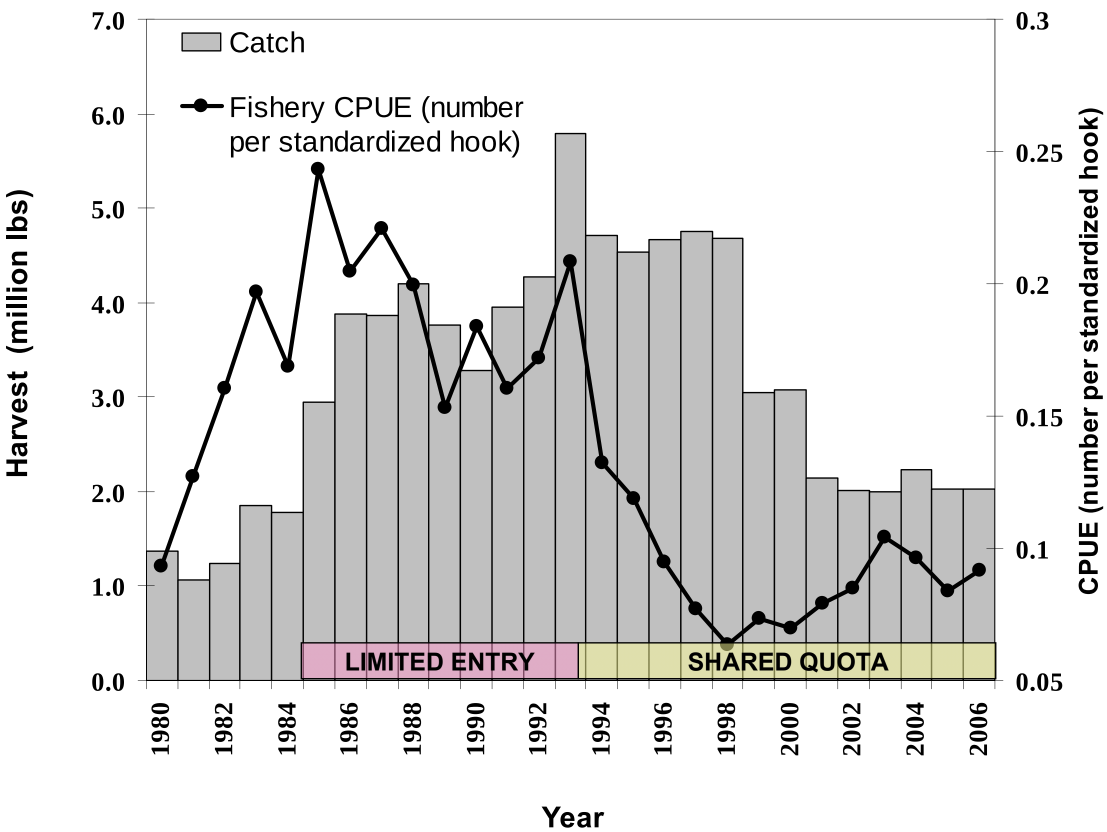

Figure 13.–NSEI sablefish fishery catch per unit of effort in number of fish per standardized hook and harvest over time. In years prior to 2000, fishery catch per unit of effort was adjusted for hook spacing and hook type for trips where hook information was provided.

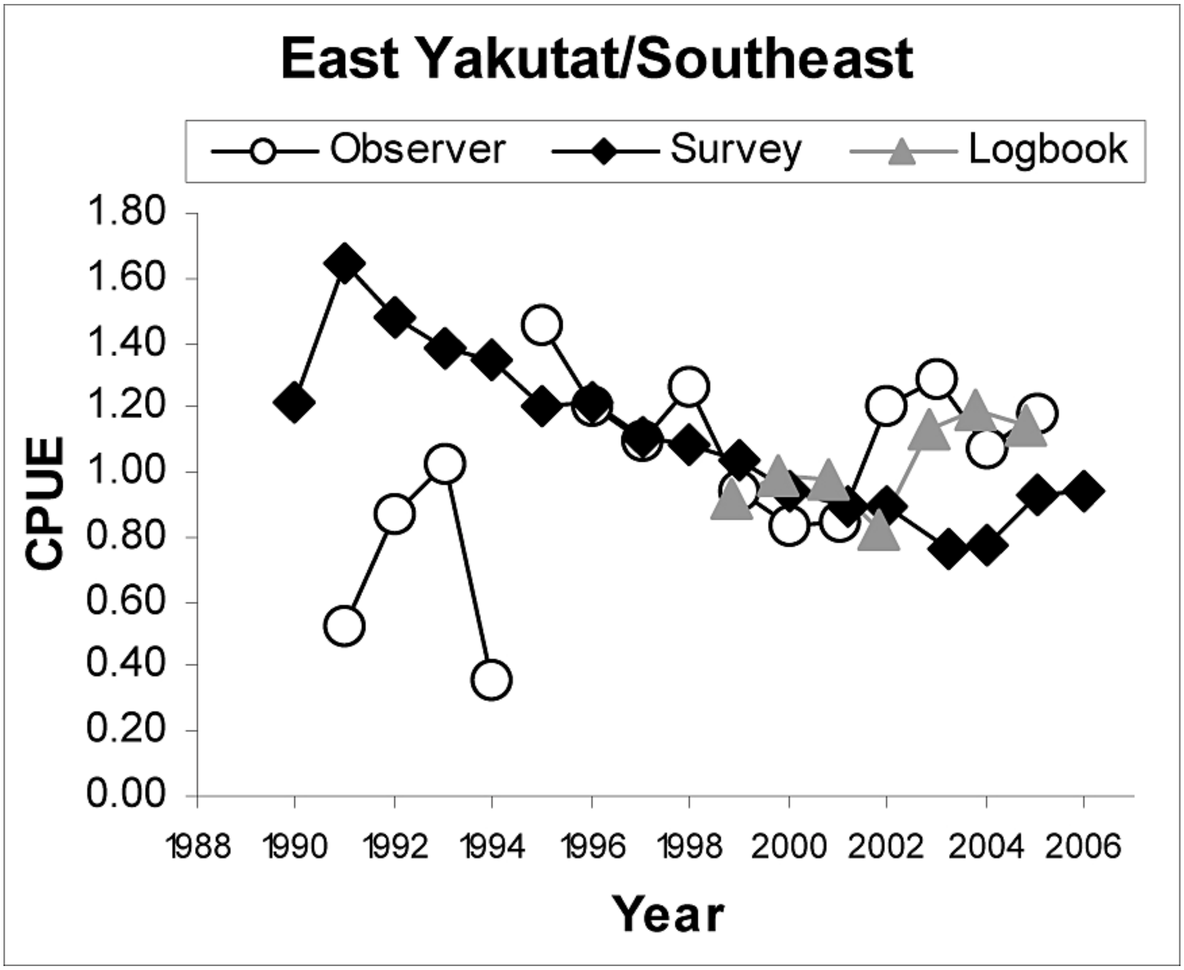

Figure 14.–Average CPUE (pounds/hook) from NOAA sablefish longline fishery and NOAA longline survey for the East Yakutat/Southeast region of the Gulf of Alaska. The fishery switched from open-access to individual quota management in 1995 (taken from Hanselman et al. 2006).

APPENDIX A

Appendix A1.–Description of mark-recapture models used in the stock assessment of Northern Southeast Inside (NSEI) sablefish, 2000 to 2006. Written by Franz Mueter to fulfill requirements for a contract with the Alaska Dept. Fish and Game.

EXTENDING THE PETERSEN MARK-RECAPTURE MODEL

There was some concern that the simple Petersen estimator that was used in previous assessments may be biased and has an unrealistically small variance. Bias may arise because some or all of the underlying assumptions may be violated and the variance could be too small because any sources of uncertainty in the true number of marks "available" to the fishery are not accounted for. I therefore implemented the Petersen estimator in a Bayesian framework (Model 1) to compare with several extended models, 4 of which are presented here, that were also implemented in a Bayesian framework. The goal was to identify and, if possible, account for sources of uncertainty and bias in the estimators. The notation used in the development of models is summarized in Appendix B.1.

GENERAL MODEL DESCRIPTIONS

A total of 5 alternative models were fit that extended the simple Petersen model by including time strata, natural mortality, immigration, and auxiliary CPUE data from the fishery (Appendix B.2). Model 1 of the assessment corresponds to the Petersen estimate used in previous years. Models 2 through 4 are extensions of the Petersen estimate based on the same underlying binomial model and are all stratified by time. Strata consisted of the longline survey and 18 consecutive 5-day fishery periods (based on delivery date). For each time period *i,* the number of recaptured (clipped) fish was assumed to follow a binomial distribution: $m_i \sim Binom(n_i, p_i)$, where n_i is the number of fish examined for marks in period i and p_i is the probability of a fish being clipped. The probability p_i is equal to the proportion of the number of marks M_i in the population during a given time period: $p_i = M_i / N_i$ and both M_i and N_i are modeled as functions of initial numbers (N_1, M_1), natural mortality, and immigration. Parameter estimates were obtained in two ways. First, by maximizing the binomial likelihood over all periods (implemented in a spreadsheet) and second, the full posterior distributions of each parameter was estimated using a Bayesian model formulation implemented in WinBUGS.

The first time period for the stratified estimator was the longline survey, which was considered to have occurred on a single day (4 August, the average survey date). The fishery was divided into 18 consecutive 5-day periods for this analysis, based on delivery dates, to ensure that a minimum of 5 marked sablefish were recovered in each period. The date associated with each fishing period was the first day of the 5-day period, which roughly corresponds to the average day of capture, considering that fish are delivered approximately 1 to 4 days after being caught.

–Continued–

Based on NSEI commercial catch data the following quantities were computed for each time period:

1. total catch (C_i)
2. number of fish examined for clips (n_i)
3. number of clips that were found (m_i) in each sample of size n_i, and
4. number of days elapsed since the previous time period (t_i).

Based on these data and the model parameters, other quantities were computed as follows:

1. To account for natural mortality of marked fish between the time of the pot survey (marking) and the first period (longline survey):

$$M_1 = M_0 \exp(-\mu d) - D \qquad (1)$$

where M_0 is the initial number of marks released, d is the number of days between the middle of the pot survey and the longline survey, D is the number of known removals from NSEI prior to the longline survey or from outside Chatham Strait, and μ is the daily instantaneous mortality rate, which is 1/365 of the annual instantaneous mortality rate m.

2. To estimate the total number of sablefish and the number of marked sablefish in Chatham Strait at the beginning of each time period:

$$\begin{aligned} N_i &= \left(N_{i-1} - C_{i-1}\right)\exp(-\mu t_i) + \beta t_i \\ M_i &= \left(M_{i-1} - m_{i-1}\right)\exp(-\mu t_i) \end{aligned} \qquad (2)$$

where i=1, 2, …, 19 is the time period, i=1 is the longline survey, M_1 is from Eq. 1, N_i is a parameter of the model to be estimated, C_i is the total number of sablefish removed during period i, and m_i is the total number of marked sablefish removed during period i.

3. <u>Likelihood function</u> (Mark-recapture component of likelihood): The probability of finding m_i marked fish during period i, given the proportion of marked fish in the population (p_i) and the number of fish examined for marks (n_i), follows a binomial distribution:

$$L_i(m_i \mid p_i, n_i) = \binom{n_i}{m_i} p_i^{n_i} (1 - p_i)^{n_i - m_i} \qquad (3)$$

The proportion $p_i = M_i / N_i$ depends on parameters N_1, μ, and β through N_i (Eq. 2) and on the number of marks M_i, which is a function of the initial number of marks and natural mortality (and is not affected by immigration).

–Continued–

Assuming independence among successive "sampling" periods (5-day intervals), the total likelihood is a product of the individual likelihoods:

$$L = \prod_{i=1}^{19} L_i \tag{4}$$

In addition to obtaining maximum likelihood estimates and likelihood-based statistics for model comparisons, I also fit each model in a Bayesian context using WinBUGS. The Bayesian posterior distribution is simply the product of the likelihoods and the prior distributions. In most cases, vague priors were used, except for the natural mortality rate *m.*

Essential Aspects of Models 2 through 5:

*Model 2***:** The model includes natural mortality only, assumed to follow a normal distribution centered on 0.1 with a variance of 0.04 (Appendix C.1). No immigration was included; therefore N_1 is the only parameter to be freely estimated.

Model 3: This model includes natural mortality and immigration, which is assumed to occur at a constant rate (number of fish entering per day). Parameters estimated by the model are N_1 and β.

Model 4: This model extends Model 2 by incorporating fishery CPUE as auxiliary information. Average fishery CPUE (sablefish per hook) is calculated for each of the 5-day periods based on catch data and fishery CPUE is assumed to be proportional to total sablefish abundance ($CPUE_i$ = q * N_i) and follow a normal distribution. To estimate parameters via maximum likelihood, the normal likelihood component was included in the maximization:

$$L(CPUE_i \mid \sigma_i, q, N_i) = \frac{1}{\sigma_i \sqrt{2\pi}} \cdot \exp\left(\frac{(CPUE_i - qN_i)^2}{2\sigma_i^{\ 2}} \right) \tag{5}$$

Because the CPUE for each period was averaged across k_i individual CPUE observations (corresponding to individual "trips" or portions of a trip), the variance of the residual for each period was assumed to be inversely proportional to the number of CPUE estimates (k_i) that were available for each period:

$$\text{var}(CPUE_i) = \sigma_i^2 = \sigma^2 / k_i \tag{6}$$

(where σ^2 is an overall variance term). To estimate parameters of Model 4 (which now include q and σ), the combined likelihood components were maximized (by minimizing the sum of log-likelihoods). Both likelihood components were weighted equally (binomial likelihood for mark-recapture data and normal likelihood for CPUE data). The relative weight for the fishery CPUE data could be reduced if the data are unreliable or questionable. In addition, the model was fit in a Bayesian formulation with vague priors on all parameters except *m*, which, as before, was assumed to follow a normal distribution centered on 0.1 with a variance of 0.04.

–Continued–

Model 5: This model extended Model 3 by including fishery CPUE data in the same way that Model 4 extended Model 2. Parameters estimated by this model are N, β, m, q, and σ.

FISHERY SELECTIVITY

To account for size selectivity of the fishery, which effectively reduces the number of marks that are available to the fishery, a correction factor was computed to adjust for the proportion of marked fish that are available. Simple simulations show that the correction factor depends only on the selectivity of the fishery and the number of marks in the population by size class. For each size class, the number of fish that are vulnerable to fishing can be computed as the product of selectivity times the number of marks in that size class. Summing the number of vulnerable marks across size classes and dividing by the total number of marks released into the population gives the desired correction factor of proportion of marked fish available to fishery. Because selectivity by size has not been estimated for NSEI, fishery selectivity at size were computed based on size-at-age and selectivity-at-age information from the federally managed IFQ fishery as summarized in Hanselman et al. (2006). The fishery uses the same longline gear and has been assumed to have a similar selectivity to the Chatham Strait fishery. Average size-at-age data were converted to average age at size, which was then used to compute selectivity by size class (center of size class) based on the average age in this size class.

The number of clipped fish in each size class and the estimated selectivity at size are summarized in Appendix B.3. Summing the proportion of clipped fish available to the fishery across size classes and dividing by the total number of clipped fish resulted in a correction factor of 0.748. Therefore, approximately 75% of clipped fish are available to the fishery if both marked and unmarked fish have the same selectivity pattern. However, size composition data suggest that clipped fish have a higher selectivity than unclipped fish in a given size, particularly at smaller sizes, suggesting that clipped fish are retained while other small sablefish tend to be discarded.

INCLUDING NATURAL MORTALITY

As a precautionary measure and to remove a possible source of bias, natural mortality was included between the time fish are marked and the time they are recaptured by the fishery in all Models 1 through 5. The fishery currently extends over approximately 3 months and the time elapsed between marking (pot survey) and recapture in the fishery is at least 2 months and can be up to 5 months. This extended duration implies that the assumption of closure will almost certainly be violated. One obvious violation is through natural mortality (e.g. predation) that is likely to occur throughout this period. Natural mortality reduces the number of marks in the population and will therefore tend to reduce the number of marks recovered. Consequently, the Petersen estimator tends to overestimate abundance if the number of available marks (counted at the time of release, prior to mortality occurring) is not discounted for mortality. While it is largely unknown when natural mortality occurs, as a precautionary approach it was assumed to occur throughout the year. Therefore, natural mortality was included in Models 1 through 5 to discount both the number of marks in the population and the total number of sablefish. The best available evidence suggests that annual natural mortality of sablefish is around m = 0.1 (see discussion and references in Hanselman et al. 2006), which translates into a daily instantaneous mortality of $\mu = 0.1/365 = 0.000274$.

–Continued–

INCLUDING NATURAL MORTALITY (CONTINUED)

Emigration has the same effect as natural mortality by removing both marked and unmarked fish from NSEI. The assumed rate of $m = 0.1$ therefore includes both natural mortality and emigration. Because there is uncertainty about this rate, moderate variability in m was allowed in each of the models and was found to have little effect on the results. I present results that allow for some variability in m (in the form of a relatively narrow prior distribution with mean 0.1 and standard deviation 0.02, see Appendix C.1).

TEMPORAL STRATIFICATION

Because of an apparent and significant trend in the ratio of marked to unmarked fish in the fishery catches over time (Appendix C.2), the Petersen estimator was stratified by time period in Models 2 through 5. To stratify by time, the fishing season was divided into 5-day periods based on date of delivery for a total of 18 periods or strata, denoted by subscript i. The longline survey was treated equivalently as a single stratum. The number of fish examined for marks (n_i) and the number of marks recovered by period (m_i) were then computed. The number of marks available at the beginning of each period (M_i) was estimated based on the initial number of marks released (minus known removals from outside NSEI or other fisheries) and the assumed natural mortality rate. Using m_i, n_i, and M_i, the usual Petersen estimator could be computed separately for each time period (Appendix C.3) and combined in a stratified estimator. As expected from the observed pattern in the ratio of marked to unmarked fish, the stratified Petersen estimates increase over time. A major goal of Models 2 through 5 is to capture and account for this apparent increasing trend. To be able to compare different models and describe uncertainties in the parameter estimates, Models 1 through 5 were fit using both a likelihood-based approach (for model comparisons) and a Bayesian approach that incorporated prior information and additional parameter uncertainty.

The first extension of the Petersen estimator therefore consists of a time-stratified estimator of abundance (abundance at the beginning of the fishery, N_1, or average abundance, $\overline{N}$) that accounts for natural mortality (Model 2). Parameters of Model 2 include initial abundance N_1 and natural mortality m (which is estimated independently and highly constrained in the model).

–Continued–

INCLUDING IMMIGRATION

Model 3 included immigration into Chatham Strait. Immigration increases the number of unmarked fish in Chatham Strait and could therefore account for the observed decrease in the ratio of marked to unmarked sablefish (Appendix C.2). Some immigration of sablefish into NSEI is likely, as tagging studies indicate movement of sablefish between Chatham Strait, Clarence Strait, the Gulf of Alaska, and British Columbia (Maloney and Heifetz 1997). Immigration was included in Model 3 by assuming a daily constant immigration rate β (number of fish entering Chatham Strait per day). This increases the modeled population size at the beginning of each fishery period (N_i) but does not affect the number of marks (M_i). Parameters of Model 3 are average abundance ($\overline{N}$), daily immigration (β), and natural mortality (m). As before, m was narrowly constrained around 0.1, while $\overline{N}$ and β were freely estimated by the model. I estimated $\overline{N}$ instead of N_1 in this model because immigration increases the number of fish available to the fishery. If the fishing quota were based on N_1, fisherman would essentially be unable to exploit the portion of the population that enters Chatham Strait after the beginning of the fishery. Using average abundance (averaged across the 18 fishing periods) provides a more robust measure of the exploitable population because it is less sensitive to variations in the estimated immigration rate than either initial abundance (N_1) or final abundance (N_{18}) and because it is comparable to the Petersen estimator, which averages across all time periods by pooling data. As an alternative, the initial abundance could be used in all cases.

INCLUDING FISHERY CPUE DATA

As a further extension to the above models and to better approximate the apparent seasonal trend in abundance, fishery CPUE was included as auxiliary data in Models 4 and 5. While models with immigration suggest an increase in abundance over time, the fishery CPUE values suggest a stable or decreasing trend in abundance (density) over time (Appendix C.4). Fishery CPUE (number of sablefish per 1000 standardized hooks) was computed for each trip using counts of fish from port sampling and numbers of hooks from logbooks. For trips that had no sablefish counts, total catch weights were converted from fish tickets to numerical abundance by dividing total catch (in lbs) by the mean weight of a fish across the season (calculated by dividing fish ticket weights of trips counted back in full by the number of fish counted). The average CPUE was computed by stratum (5-day period) across all trips delivered during the 5-day period.

To utilize the information available in the fishery CPUE data, versions of Model 2 and Model 3 were constructed that included the fishery CPUE data, which are Models 4 and 5. I assumed that fishery CPUE was proportional to total sablefish abundance in each time period ($CPUE_i$ = q * N_i) and that the difference between the observed and the model-estimated CPUE followed a normal distribution. The estimated time trend in abundance was then tuned to the fishery data by maximizing the normal likelihood (equivalent to minimizing the sum of squared differences between the observed and estimated $CPUE_i$).

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The models including fishery CPUE data were fit to both the mark-recapture and fishery CPUE data by maximizing the combined likelihood, which consists of a binomial likelihood component for the mark-recapture data and a normal likelihood for the fishery CPUE data. Both likelihood components received equal weights in the combined likelihood, thus fishery CPUE and mark-recapture data contribute equally to the parameter estimation. The two additional models including fishery CPUE data were equivalent to Models 2 and 3, but include the fishery CPUE data which requires the estimation of 2 additional parameters corresponding to the catchability coefficient q and the standard deviation (σ) of the CPUE data. Model 4 includes no immigration and estimates a total of 4 parameters (N_1, q, σ, m), where m is highly constrained (Appendices B.2 and B. 4). Model 5 extends Model 4 by also including a parameter for daily immigration (β). Essential characteristics of Models 1–5 are compared in Appendix B.2.

ACCOUNTING FOR FISHERY SELECTIVITY

An important source of potential bias in the above models may arise from fishery selectivity due to either gear selectivity or "high grading" (i.e. discarding of small fish). There is strong evidence for size selectivity in the fishery based on other fisheries and on the relative size composition of sablefish in the pot fishery, longline survey, and longline fishery. For example, NOAA stock assessments for the Gulf of Alaska sablefish fishery estimate a pattern of selectivity at age that implies low selectivity at small sizes and full selectivity at larger sized (logistic function). Size composition estimates in Chatham Strait from different gears employed in the past suggest that pot gear has a higher selectivity for smaller fish than longline gear and that the fishery selects against smaller fish relative to the longline survey, implying some high grading or a different spatial distribution of the fishery (i.e. in areas with more larger fish, e.g. deeper stations on average). This pattern of size compositions was also observed in 2006 (Appendix C.5). It is unlikely that the difference is due to differences in depths fished because the depth distribution is similar among the 2 surveys and the fishery (Appendix C.6), although the fishery extends into both shallower and deeper areas compared to the longline survey.

In spite of the difference in apparent size selectivity between the fishery and the pot survey, the size distribution of recaptured (tagged) sablefish greater than 55 cm during the fishery is very similar to that of released fish from the pot survey (Appendix C.7), suggesting that all size classes greater than 55 cm that are marked by the pot survey are fully selected by the fishing gear. In previous years, when all fish greater than 50 cm were tagged, length distributions have suggested that all size classes greater than 50 cm that are marked by the pot survey are fully selected by the fishing gear. The best explanation at the current time for the difference in the length distributions of the marked fish recovered in the commercial fishery and the sample of all fish captured in the commercial fishery is that all size classes caught by pot gear are "vulnerable" to the fishery and all clipped/marked fish are retained, but other small fish tend to be discarded. Though anecdotal, a comparison of the percent of 2005 double-marked (tagged and clipped) 51–55 cm fish recovered by the 2005 fishery (10.4%) with that of 2006 single marked (clip-only) 51–55 cm fish recovered by the 2006 fishery (4.2%) suggests that untagged (clip-only) small fish may only be kept half as often as tagged fish. This differential retention of small marked and small unmarked fish could explain the differences in length distributions observed.

–Continued–

Accounting for Fishery Selectivity (Continued)

The implication is that when all marked fish are tagged (i.e. there are no fish that are just clipped) total "vulnerable" population size is estimated, but only a portion of the vulnerable population is actually exploited because of high grading. In other words, the total population exploitable by the commercial gear is estimated, but the population exploited by fishermen using the commercial gear is overestimated. The amount of high grading depends on factors such as size composition of the population, gas prices, and duration of the trip, and likely varies year to year.

Biases due to selectivity will affect abundance estimates from all Models (1 through 5). Some simple simulations were conducted to explore the use of a correction factor to include in each of the above models to account for the estimated effect of fishery selectivity on estimates of abundance. This investigation into the effects of selectivity on abundance estimates was still in progress at the time the 2007 AHO was set, so was not ready to implement in this year's assessment.

Other Models and Adjustments not Implemented

Several alternatives to the above models were explored. One alternative for explaining the observed decrease in the ratio of marked to unmarked fish is that marked sablefish experience higher mortalities than unmarked fish. To examine this possibility a model that incorporates differential mortality between marked and unmarked fish was fit. The resulting model provided a much better fit but implies a substantially higher mortality rate of marked fish compared to unmarked fish (approximately 10 to 20 times higher mortality for marked fish). Such a large mortality of marked fish seems unrealistic, given that in previous years a large number of tags were recovered in subsequent years. The mortality parameter was also difficult to estimate and was highly uncertain; therefore this model was not further developed this year. If this model were true and marked fish have a higher mortality, it could have important consequences for estimates of abundance. The model implies that the true number of marks available in the population (M_i) is much lower than estimated by other models that assume the same mortality rate for marked and unmarked fish. Because of the lower estimates of M_i, estimated abundances are substantially lower using this model.

Several other model runs were completed to freely estimate natural mortality. However, they resulted in highly unrealistic and extremely uncertain estimates for m (ranging from -5 to +5). Therefore, these models are not fully described here. However, the consequences of uncertainties in m were evaluated by allowing m in the Bayesian analysis to vary from approximately 0.05 to 0.15 and assessing the effect on the resulting estimate, which was found to be relatively minor. These difficulties were not unexpected because natural mortality is notoriously difficult to estimate in stock assessment models. Our results suggest that the effect of natural mortality on abundance estimates is relatively minor.

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MODEL ESTIMATES AND GOODNESS OF FIT

Abundance estimates were very similar across models because all models had a similar structure and used the same set of mark-recapture data. Results of Models 1–5 are summarized in Table B-4. The frequentist and Bayesian (Model 1) implementation of the Petersen estimator gave nearly identical results. For consistency in methodology, Models 2–5 were compared with Model 1 (the Bayesian implementation of the Petersen estimator) rather than the frequentist implementation of the Petersen estimator. The simple time-stratified estimate (Model 2) was somewhat higher than the simple Petersen estimate (Model 1), in spite of assuming a reduction in the number of marks available to the fishery by including natural mortality. However, Model 2 appeared inadequate because it could not reproduce the decreasing trend in the ratio of marked to unmarked individuals over time (Appendix C.2). This was apparent in the residual trend in the number of marks (observed – expected, Appendix C.8), as well as in a comparison of the trend in estimated abundance (N_i) to the corresponding Petersen estimates for each period (Appendix C.9). Relative to the fishery, the number of marks recaptured in the longline survey was much lower than expected based on this (and other) models, suggesting either that the number of marks are underestimated in the longline survey or overestimated in the fishery. However, the number of marks is generally highly variable among periods and may have differed due to chance. In previous years, estimates from the longline survey were typically lower or similar to the estimate from the fishery. Since the sampling design did not change in 2006, there is no *a priori* reason to believe that the low number of recovered marks in the longline fishery in 2006 was due to any differences between the portion of the sablefish population sampled by the longline survey and the portion sampled by the fishery.

With immigration included (Model 3), the fit improved markedly (Appendix C.10) and results suggested a substantial increase in sablefish abundance over time due to immigration of almost 12,000 sablefish per day into Chatham Strait. The improved model fit was evident in the improved likelihood and the reduced value of the model selection criterion AIC (Appendix B.4). The average abundance over the fishing season from Model 3 was very similar to the estimate of initial abundance from Model 2. However, the estimated immigration rate of almost 12,000 sablefish per day (95% credibility interval: 3,900–20,500) implied an increase in total abundance from 2.18 million sablefish at the beginning of the fishing season to 2.89 million sablefish at the end of the fishing season (Appendix C.10) and a total immigration of >1,200,000 sablefish into Chatham Strait over the 103-day period between 4 August (middle of the longline survey) and 15 November (end of fishery). This appeared to be unreasonably high although some immigration into Chatham Strait is believed to occur. Moreover, it is unlikely that immigration occurs at a steady rate over this entire period. Therefore, Model 3 is not recommended in spite of the improved statistical fit until independent estimates of immigration into Chatham Strait can be examined.

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To "anchor" the apparent within-season trend in abundance, Models 4 and 5 used available CPUE data from the fishery. Fishery CPUE data decreased over time (Appendix C.4). The decrease, although not significant (weighted linear regression: t = -1.178, p = 0.256) contrasted with the apparent increase in abundance suggested by Model 2. Model 4 (no immigration) fit the CPUE data well (Appendix C.11) but, like Model 2, had a clear trend in the mark-recapture residuals (observed minus expected recaptures). The model could not account for the observed decrease in the number of marks over the season (as evident in an obvious trend and negative residuals in the last part of the fishing season in Appendix C.12) and displayed a trend very different from the corresponding time-stratified Petersen estimates (Appendix C.13). Model 5 (with immigration) provided an improved fit to the observed number of marks (Appendix C.14) and better agreement with time-stratified Petersen estimates (Appendix C.15), but a worse fit to the catch data compared to Model 4 (Appendix C.16). The model had a slightly improved total likelihood overall and a lower AIC, thus would be preferred on statistical grounds, although the likelihood ratio test suggested that the added immigration parameter was not significantly different from zero at the 95% level (p = 0.060, Appendix B.4). The individual likelihood components confirmed that the model provided a better fit to the mark-recapture data, but not as good a fit to the fishery CPUE data (Appendix C.4). The estimated immigration rate was close to 6,000 sablefish per day, implying a total immigration of approximately 600,000 sablefish into Chatham Strait over the course of the fishing season.

UNCERTAINTY

Compared to the Petersen estimator (Model 1), additional uncertainty was introduced into Models 2 through 5 and Models 3 and 5, respectively, by including parameters for natural mortality and immigration. However, using a stratified estimator and including additional information from the fishery CPUE data in Models 2 through 5 and Models 4 and 5, respectively, allowed the possibility of reducing uncertainty about abundance. Results showed that the estimates of N_1 from Models 2 and 4 (without immigration) had very similar standard deviations to the Petersen estimator, while the average abundance estimate from models with immigration had somewhat larger standard deviations due to uncertainty associated with the extra parameter β. Allowing the natural mortality rate m to vary randomly between about 0.05 and 0.15 in Models 2 to 4 had very little effect on the estimates and standard errors, therefore the estimates are robust to a reasonable range of values for natural mortality.

A potentially larger source of uncertainty is related to selectivity patterns in the fishery and the potential for different selectivity for marked and unmarked sablefish. The most likely effect of the observed selectivity patterns is a moderate overestimation of exploitable abundance. While a preliminary model that incorporated effects of fishery selectivity was developed (suggesting a lower abundance of sablefish and implying larger uncertainty in parameter estimates), it would be premature to use the model for management purposes at this stage.

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USING DATA FROM MULTIPLE YEARS

A final improvement of the mark-recapture estimates of abundance was attempted by including estimates over multiple years in a simple time-series model. Consistent methodology using the pot survey to mark individuals and recapturing them from the fishery, has been used since 2000 and the pot survey design and the quality of catch sampling have improved over time. The stock assessment has relied on the Petersen estimator to estimate abundance for 2001 and 2003–2006, while an exploitation rate estimator was used in 2000 and 2002 to convert total catches to total exploitable biomass. The 2000 and 2002 estimates of biomass were converted here to numerical estimates of abundance using average weight in the fishery to obtain a time series of numerical abundance from 2000 to 2006 (Appendix C.17).

The time series of estimated abundance (Appendix C.17), in spite of relatively narrow confidence intervals, displays a level of variability that may be biologically unrealistic given the life history of sablefish, which are a long-lived species with relatively low natural mortality. Therefore, adult (or exploitable) abundance in a given year is not expected to vary substantially from the previous year. Such slowly changing dynamics are commonly approximated by a first-order autoregressive process, in which the abundance in year *t* fluctuates around a long-term mean and the difference from the long-term mean depends on the difference in year *t-1* through a parameter ϕ plus some random deviation due to estimation errors or other processes:

$$y_t = \phi \cdot y_{t-1} + \varepsilon_t \tag{7}$$

where $y_t = N_t - \overline{N}$ and $\overline{N}$ is the long-term average abundance. In this model, abundance in a given year tends to be "close" to the previous year's abundance (as long as ϕ > 0), while "reverting" towards the mean. Using 2001–2006 abundances, the model estimated a negative auto-regressive coefficient (ϕ = -0.48, se(ϕ) = 0.32), implying that the difference from the mean abundance in one year (y_{t-1}) is often opposite that of the following year (i.e. there is an oscillating pattern of abundance in the time series; see Appendix C.17). A negative auto-regressive coefficient does not make much biological sense and could be a result of using different estimators to estimate biomass in different years. The biggest changes in year-to-year abundance (the top 3 out of 6) were those between different estimators (2000 exploitation rate– 2001 Petersen, 2001 Petersen–2002 exploitation rate, 2002 exploitation rate–2003 Petersen). It is possible that the changes in estimated abundance could be partly due to differences in bias between the estimators. More notably, the standard error of 0.32 for phi means that a 95% CI easily includes 0. The fact that phi is not significantly different than zero indicates that difference from the mean abundance in one year (y_{t-1}) holds essentially no information about abundance in the following year (i.e. there was no apparent autocorrelation in the time series). Therefore the estimates from the autoregressive model ($\overline{N} + y_t$) are all close to the overall mean (fitted line in Appendix C.17). Due to the insignificance of phi, using an autoregressive estimator is not an appreciable improvement over estimating the 6 years by taking a mean abundance. Therefore, the autoregressive estimator is not recommended for stock assessment and management at this time.

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USING DATA FROM MULTIPLE YEARS (CONTINUED)

Coincidentally, the 2006 estimate is close to the mean; hence applying this estimator would not affect the estimated abundance appreciably. It is possible that this estimator might be worth revisiting as the length of the time series increases.

An autoregressive or other appropriate time series model could also be used to forecast 2007 abundances (with a confidence interval). However, given that a wealth of biological information on natural mortality, age composition, maturity and abundance of pre-recruit stages is available from the longline survey and fishery sampling, the current approach to forecasting future abundance and biomass is much more appropriate than a simple time series model, which is typically only recommended in data-poor situations.

MODEL SELECTION AND PRELIMINARY PREFERRED MODEL

Statistically, Models 3 and 5 (the models that incorporated immigration) capture the pattern in observed marks over time much better than Models 1, 2, and 4. While the immigration rate in Model 3 may be unrealistically high, the rate estimated by Model 5 seems to be more reasonable, especially considering the high uncertainty in the parameter estimate (which included 0). Although the immigration parameter was only marginally significant in Model 5 ($p = 0.060$), this model provides a considerably better fit to the mark-recapture data (compare the mark-recapture likelihood component values 56 versus 59 in Appendix B-4). Because the mark-recapture data is probably more reliable than the fishery CPUE data, the author (Franz Mueter) suggests Model 5 as the preferred model (it also happens to be a little more conservative). The Bayesian model with a correction for fishery selectivity is a promising model that probably captures the true uncertainty much better.

APPENDIX B

Appendix B1.–Notations for models used in the 2006 NSEI sablefish stock assessment. This table was used in Franz Mueter's analysis of NSEI sablefish stock assessment, while under contract with the Alaska Department of Fish and Game.

Parameter	Definition
N_0	Number of sablefish in Chatham Strait at the time of marking
M_0	Number of marks released
D	Known number of marks removed that are not available to either the LL survey or to the fishery (tags from halibut fishery, from outside, etc.)
B	Number of fish entering Chatham Strait between pot survey and LL survey (unknown)
m	Annual instantaneous rate of natural mortality (may include emigration)
μ	Daily instantaneous rate of natural mortality (may include emigration) = $m/365$
δm	Difference in mortality rate between marked and unmarked fish, hence instantaneous mortality of marked fish is ($m + \delta m$)
i	Subscript for time period i, which may refer to longline survey ($i = 1$) or to one of 18 consecutive 5-day fishery periods (based on time of landing, $i = 2,\ldots,18$)
N_i	Number of sablefish in Chatham Strait at the beginning of time period i
M_i	Number of marked sablefish in Chatham Strait at the beginning of time period i
t_i	Total number of days between beginning of period i-1 and beginning of period i
C_i	Total catch (number of sablefish removed) reported during period i
n_i	Observed catch (number of marked + unmarked sablefish that were checked for clips) during period i ($n_i < C_i$)
m_i	Number of marked fish recovered during period i
β	Number of unmarked fish entering Chatham Strait from outside per day
p_i	Proportion of marked fish in the population at beginning of period i (= M_i / n_i)
q	Catchability coefficient for the fishery relating fishery CPUE in period i to the abundance of sablefish $CPUE_i = q * N_i$

Appendix B2.–Different models used to fit the NSEI sablefish data. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.

Model	Description	Parameters
1	Petersen estimator	N
2	Time-stratified estimator with natural mortality	N, m
3	Time-stratified, natural mortality, and immigration	N, β, m
4	Time-stratified estimator with natural mortality, including fishery CPUE data	N, m, q, σ
5	Time-stratified estimator with natural mortality and immigration, including fishery CPUE data	N, β, m, q, σ

Notes:

1. natural mortality was fixed at 0.1 or highly constrained in all models

2. Average abundance across the fishing season ($\overline{N}$) was estimated in models 1, 3, and 5, whereas initial abundance at the beginning of the season (N_I) is estimated by models 2 and 4.

Appendix B3.–Number of clipped fish and selectivity at size estimated from 2006 NOAA sablefish assessment (Hanselman et al. 2006). Size classes denote the center of each 20 mm size class.

Size class	No. of clipped fish	NOAA fishery selectivity
475	0	0.015
495	1	0.027
515	223	0.049
535	352	0.096
555	352	0.191
575	438	0.369
595	541	0.605
615	658	0.800
635	739	0.914
655	664	0.969
675	605	0.991
695	478	0.998
715	338	1.000
735	239	1.000
755	131	1.000
775	101	1.000
795	66	1.000
815	48	1.000
835	29	1.000
855	7	1.000
875	17	1.000
895	17	1.000
915	10	1.000
935	5	1.000
955	5	1.000
975	3	1.000
995	3	1.000
1,015	0	1.000
1,035	2	1.000

Appendix B4.–Summary of model results and model comparisons for 2006–2007 NSEI sablefish stock assessment. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.

	Model				
	1	**2**	**3**	**4**	**5**
Are Following Parameters in Model ?					
Immigration	No	No	Yes	No	Yes
fishery CPUE	No	No	No	Yes	Yes
natural mortality	No	Yes	Yes	Yes	Yes
Parameter estimates [a]					
N (mean)	2,428,000	2,492,000[b]	2,477,000[c]	2,487,000[b]	2,364,000[c]
m	0	0.1	0.1	0.1	0.1
Immigration (β)	—	—	11,950	—	5,858
catch coefficient (q)	—	—	—	4.01E-05	3.97E-05
Std.err. (CPUE) (σ)	—	—	—	55.88	61.66
Posterior distribution of abundance [d]					
2.5th percentile	2,214,000	2,289,000	2,227,000	2,288,000	2,145,000
5th percentile	2,249,000	2,320,000	2,262,000	2,319,000	2,176,000
Mean	2,428,000	2,492,000	2,477,000	2,487,000	2,364,000
95th percentile	2,607,000	2,675,000	2,713,000	2,668,000	2,570,000
97.5th percentile	2,641,000	2,711,000	2,763,000	2,706,000	2,618,000
standard error	108,933	107,700	137,200	107,100	119,800
Maximum likelihood components (negative log-likelihoods)					
MR data		58.984	54.627	58.984	56.022
fishery CPUE		—	—	74.807	76.003
Total likelihood	—	**58.984**	**54.627**	**133.790**	**132.025**
Number of parameters		1	2	3	4
Sample size		19	19	37	37
AIC [e]		120.2026	114.0036	274.3079	273.3008
LRT [f]		—	8.713751	—	3.529766
p-value [f]		—	0.003158	—	0.060276

[a] Model 1: Petersen estimator. Models 2–5: Bayesian model estimates with informative prior on *m*.

[b] Estimated abundance at the beginning of the 2006 season (N_1)

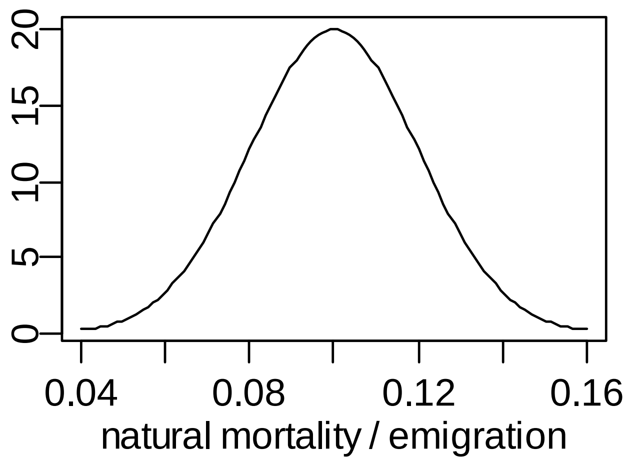
[c] Estimated stratified abundance over the 2006 season (N_{bar})

[d] Percentiles for Model 1 based on normal distribution and standard error.

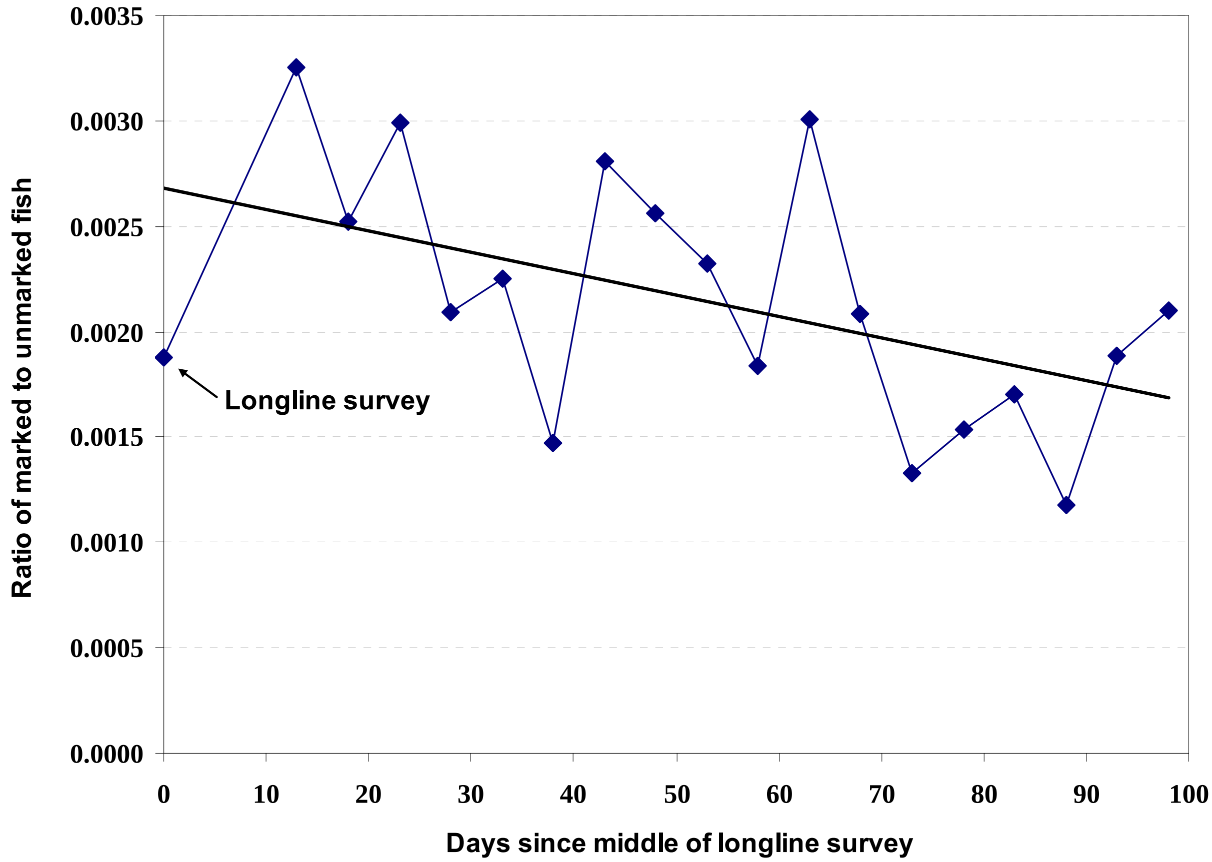
[e] AIC: Small-sample Akaike Information Criterion for model comparisons

[f] Likelihood-ratio test statistic for comparing models 2 vs. 3 and 4 vs. 5, respectively, with associated p-values

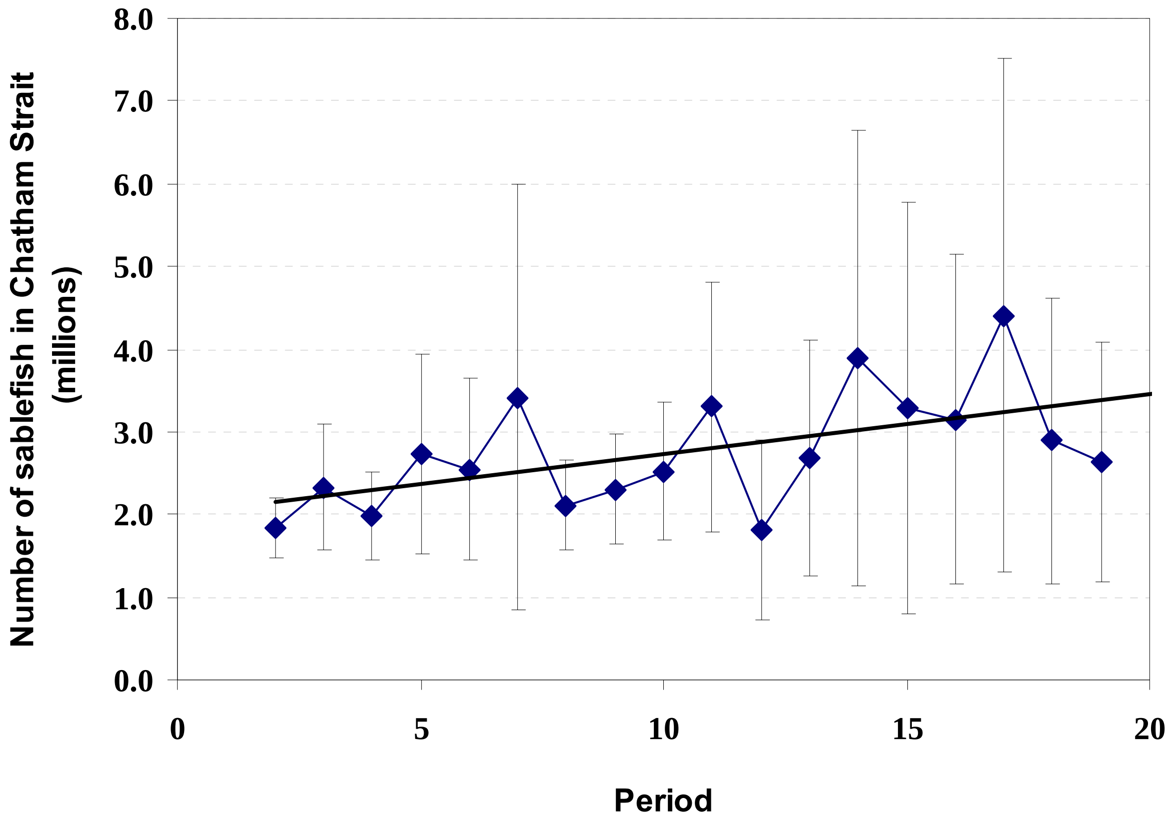
APPENDIX C



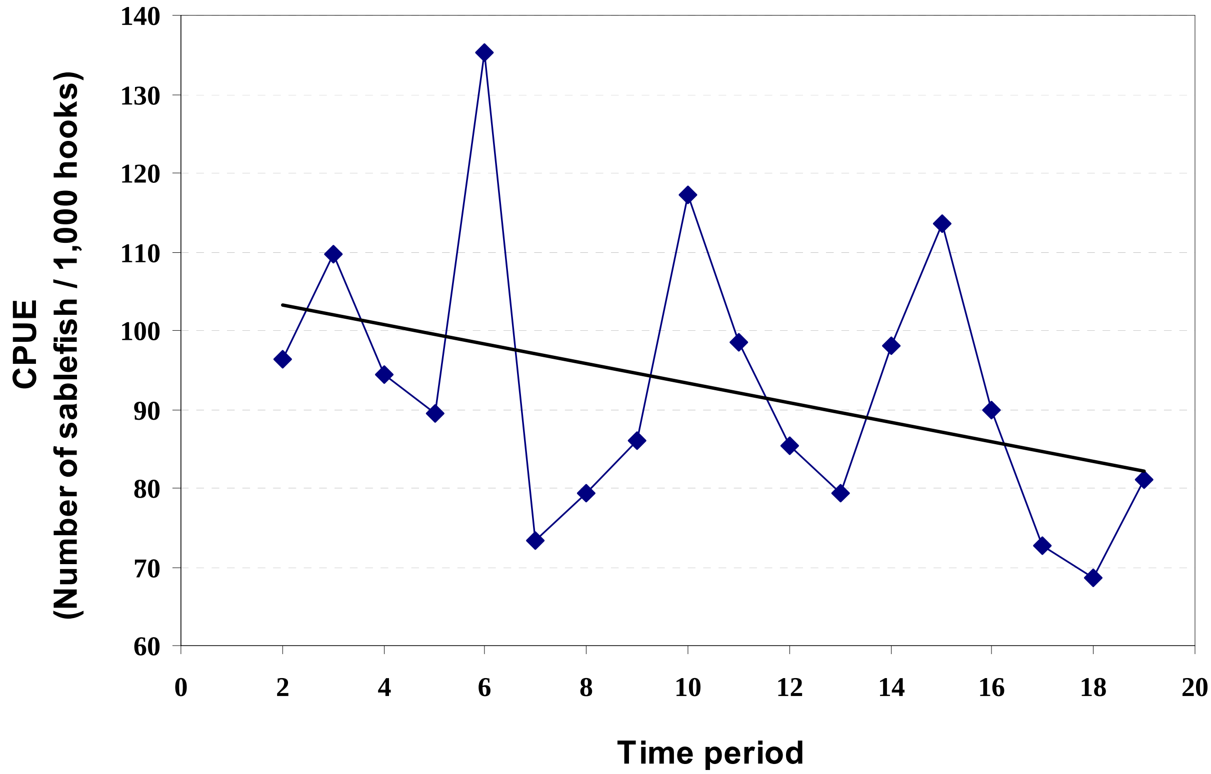
Appendix C1.–Prior distribution on annual instantaneous natural mortality rate *m* used in Models 2 through 5. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



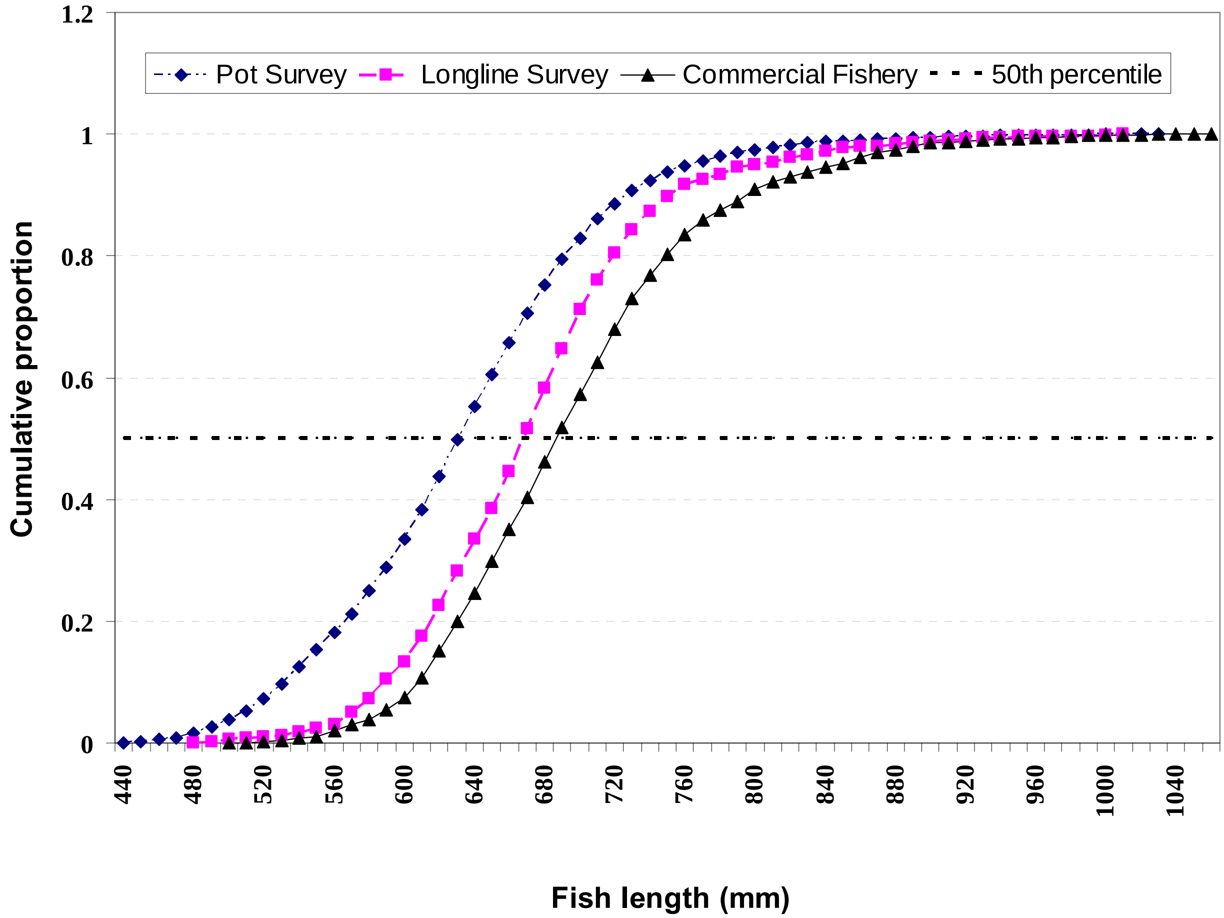
Appendix C2.– Change in the ratio of marked to unmarked fish caught in the fishery over the course of the fishing season with linear fit ($F_{1,17} = 5.542$, $p = 0.0309$, $R^2 = 0.26$). Ratios were computed for the longline survey and for each of 18 consecutive 5-day periods during the fishery, based on delivery date. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



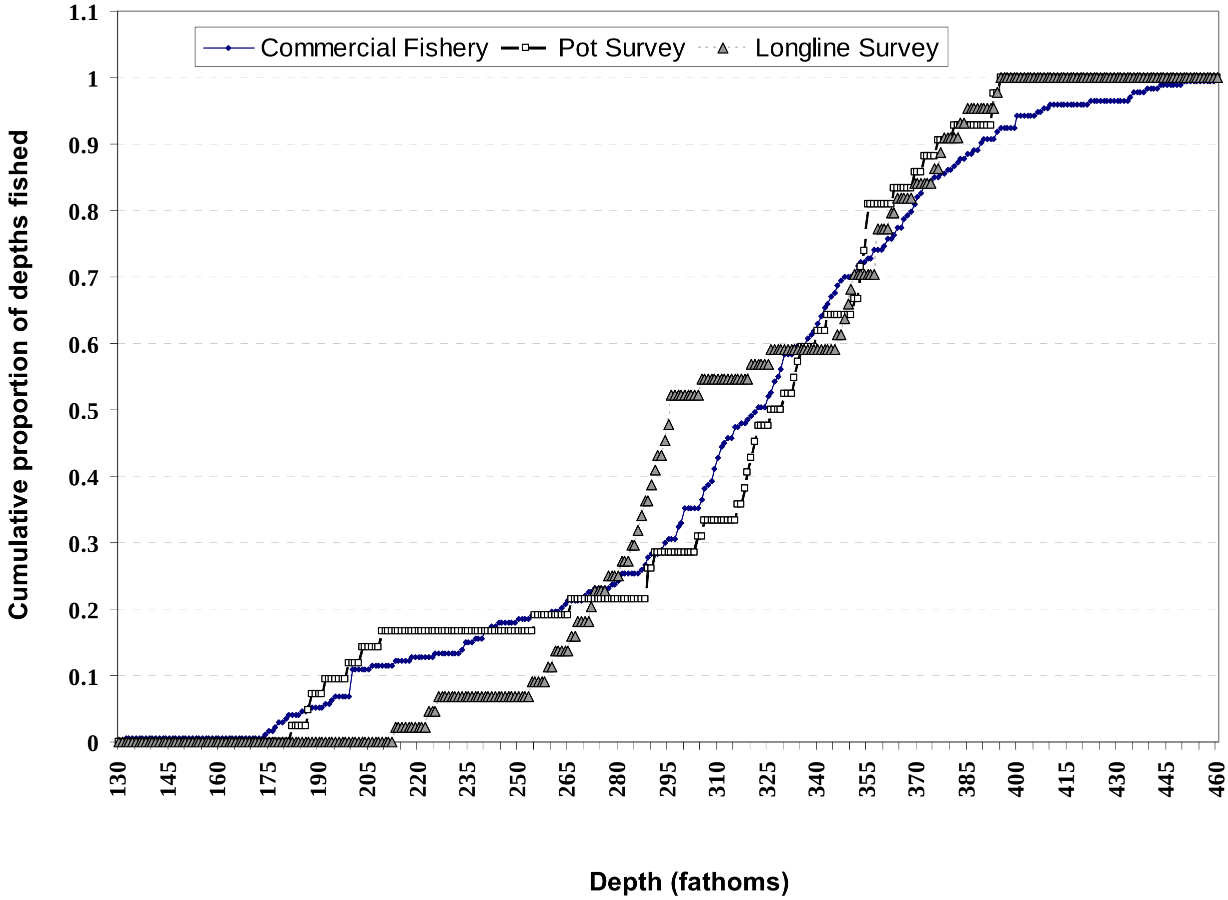
Appendix C3.–Time-stratified Petersen estimates of abundance of sablefish in Chatham Strait using marked and unmarked sablefish counted during consecutive 5-day periods in the fishery with approximate 95% confidence intervals and linear time trend (weighted least-squares regression). Estimates and confidence intervals for each period are based on Chapman modification of the Petersen estimator and its approximate variance (2 * standard deviation). This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



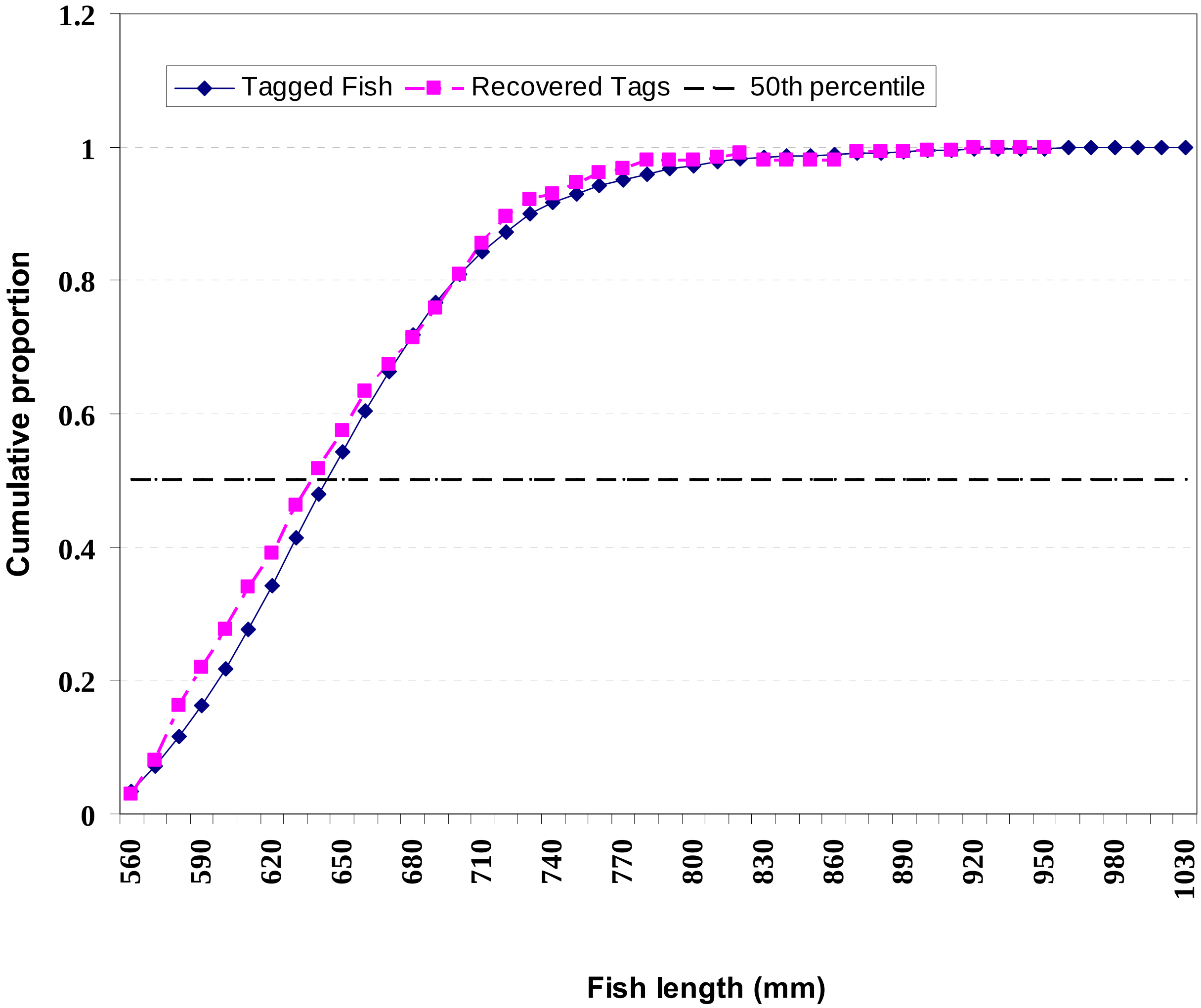
Appendix C4.–Fishery CPUE averaged across deliveries (trips) occurring within one of 18 consecutive 5-day periods with linear regression line (Linear regression weighted by the number of trips within each period: $t = -1.178$, $p = 0.256$. Number of trips contributing to a period's average was generally much lower in later periods, which therefore received lower weights in the regression). This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



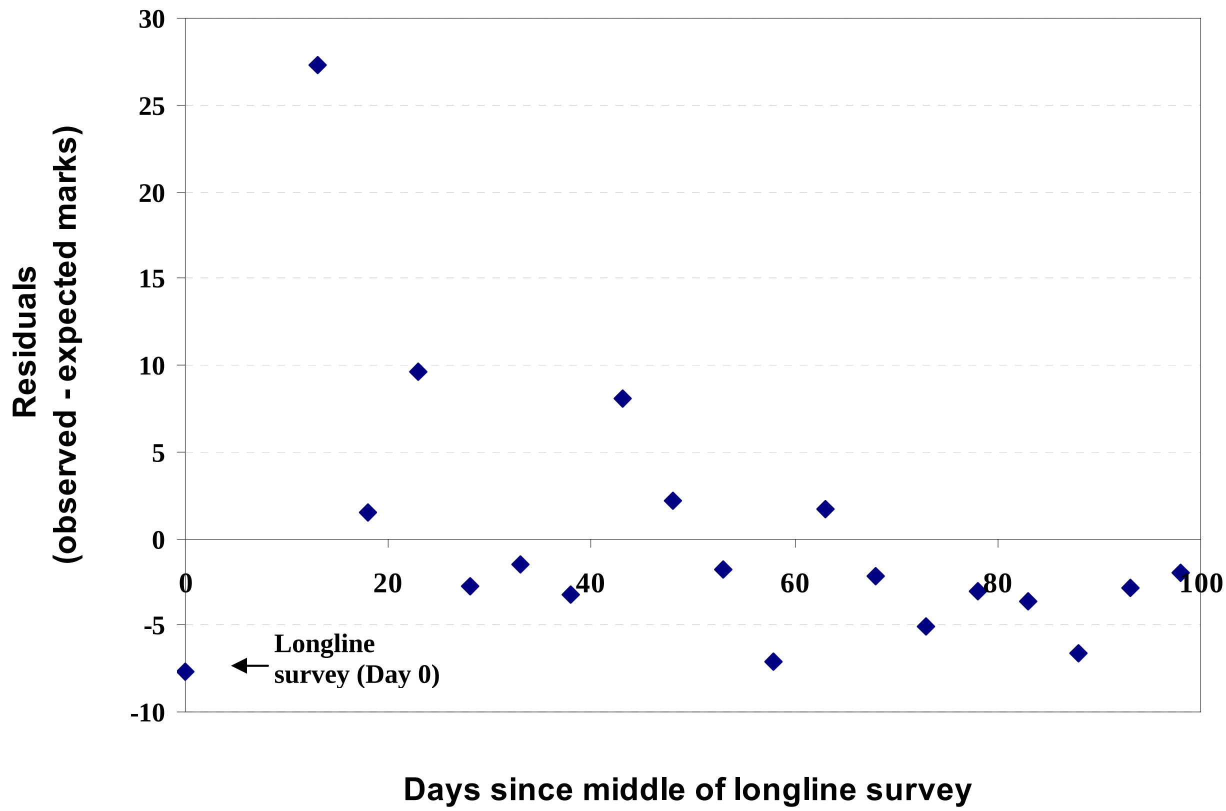
Appendix C5.–Cumulative length-frequencies of all sablefish sampled during pot survey, longline survey, and fishery in 2006 (50th percentile indicated). This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



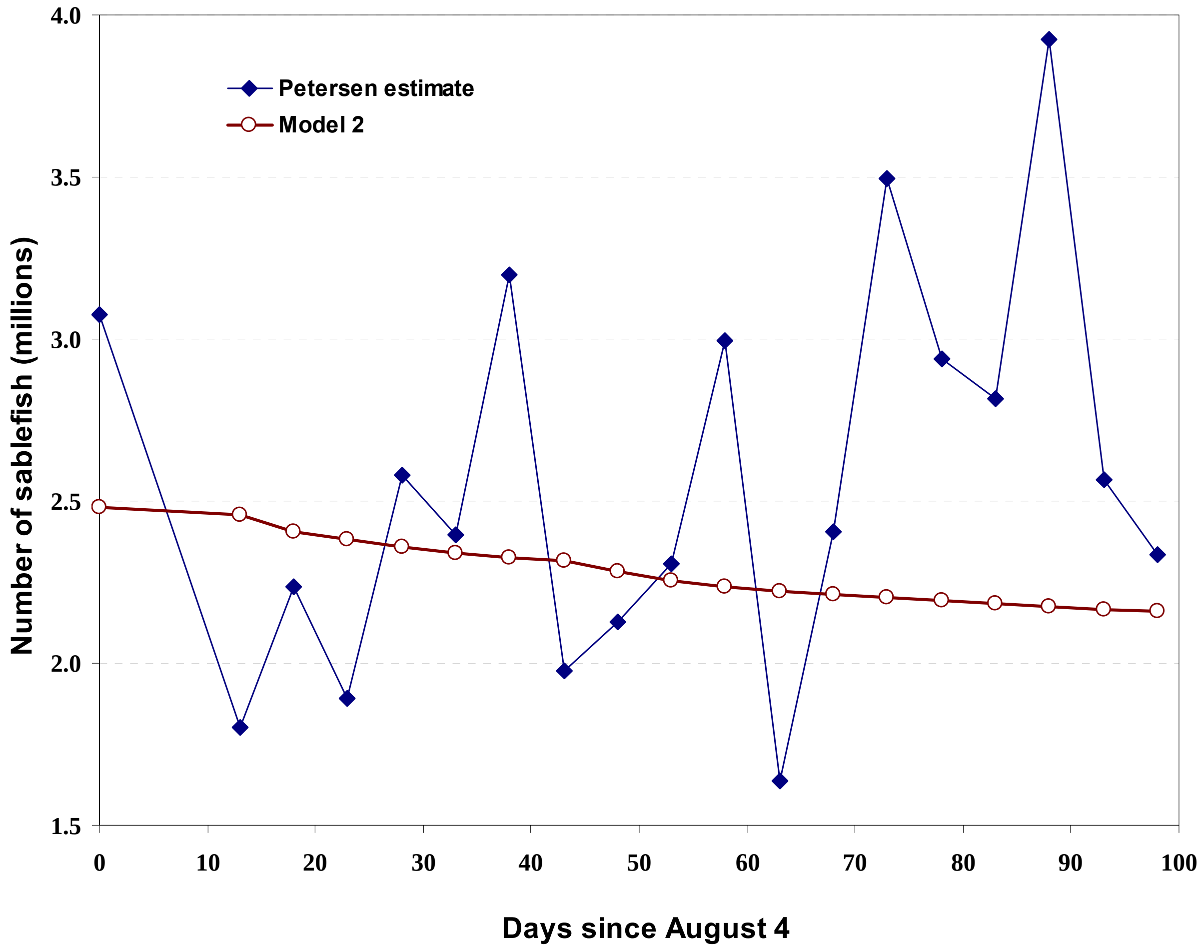
Appendix C6.–Cumulative depth distribution of pot and longline survey stations and fishery trips (n = 42, n = 44, and n = 173, respectively). Kolmogorov-Smirnov tests do not indicate significant differences, except a marginally significant difference between longline survey and fishery (D = 0.216, p = 0.075). This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



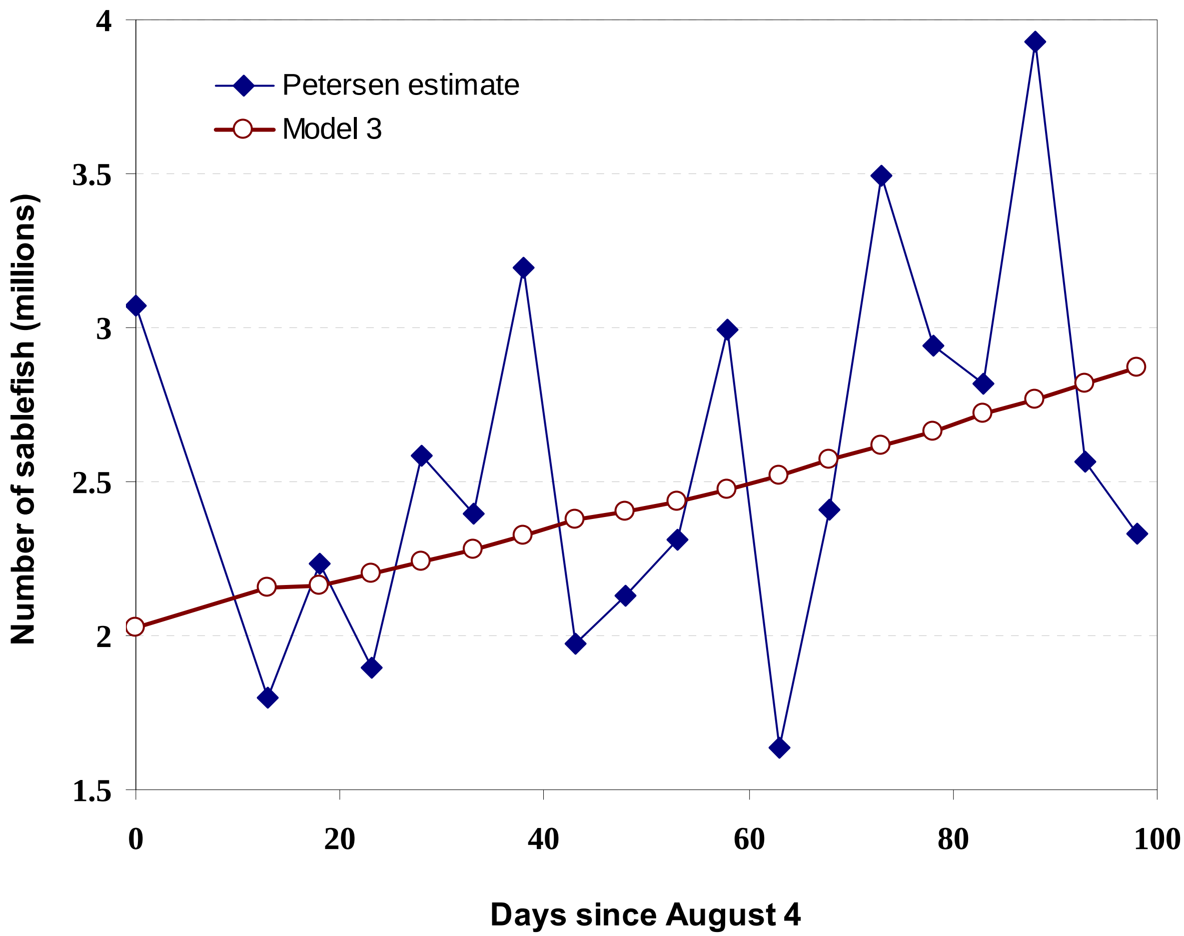
Appendix C7.–Cumulative size distribution of tagged fish released in the survey and recaptured in the fishery (Kolmogorov-Smirnov test: D 0.063, $p = 0.053$). This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



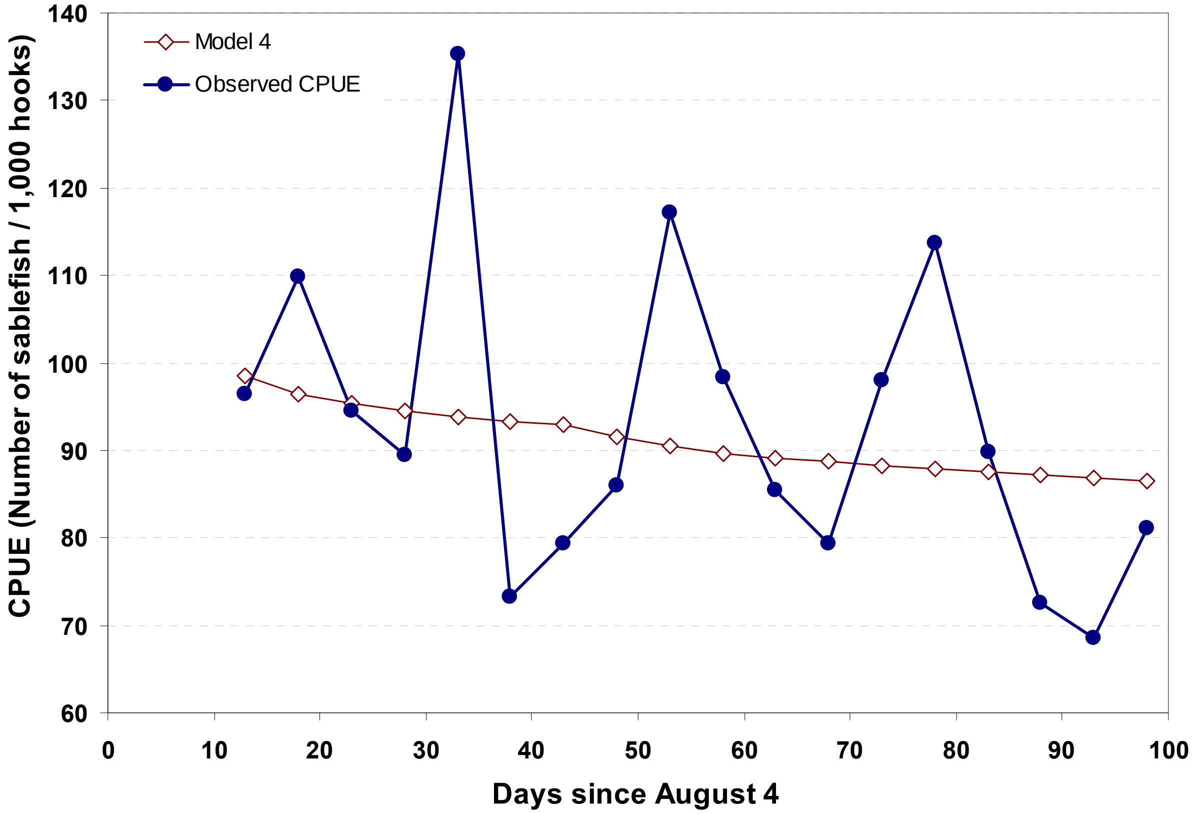
Appendix C8.–Trend in observed minus expected number of marks by sampling period (longline survey and 18 fishery periods) based on Model 2. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



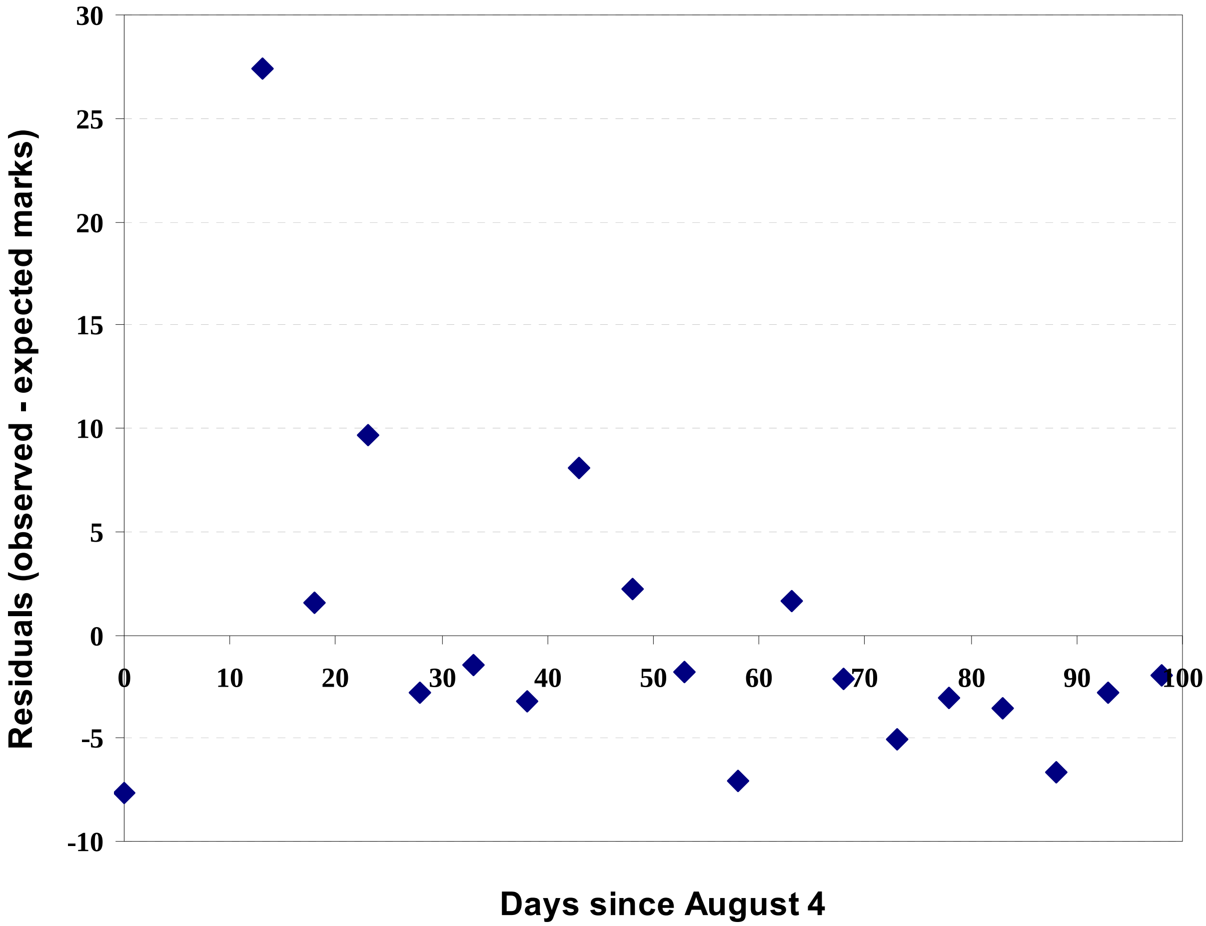
Appendix C9.–Model 2 estimated trend in sablefish abundance and corresponding time-stratified Petersen estimates of abundance for longline survey and 18 consecutive 5-day fishery periods. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



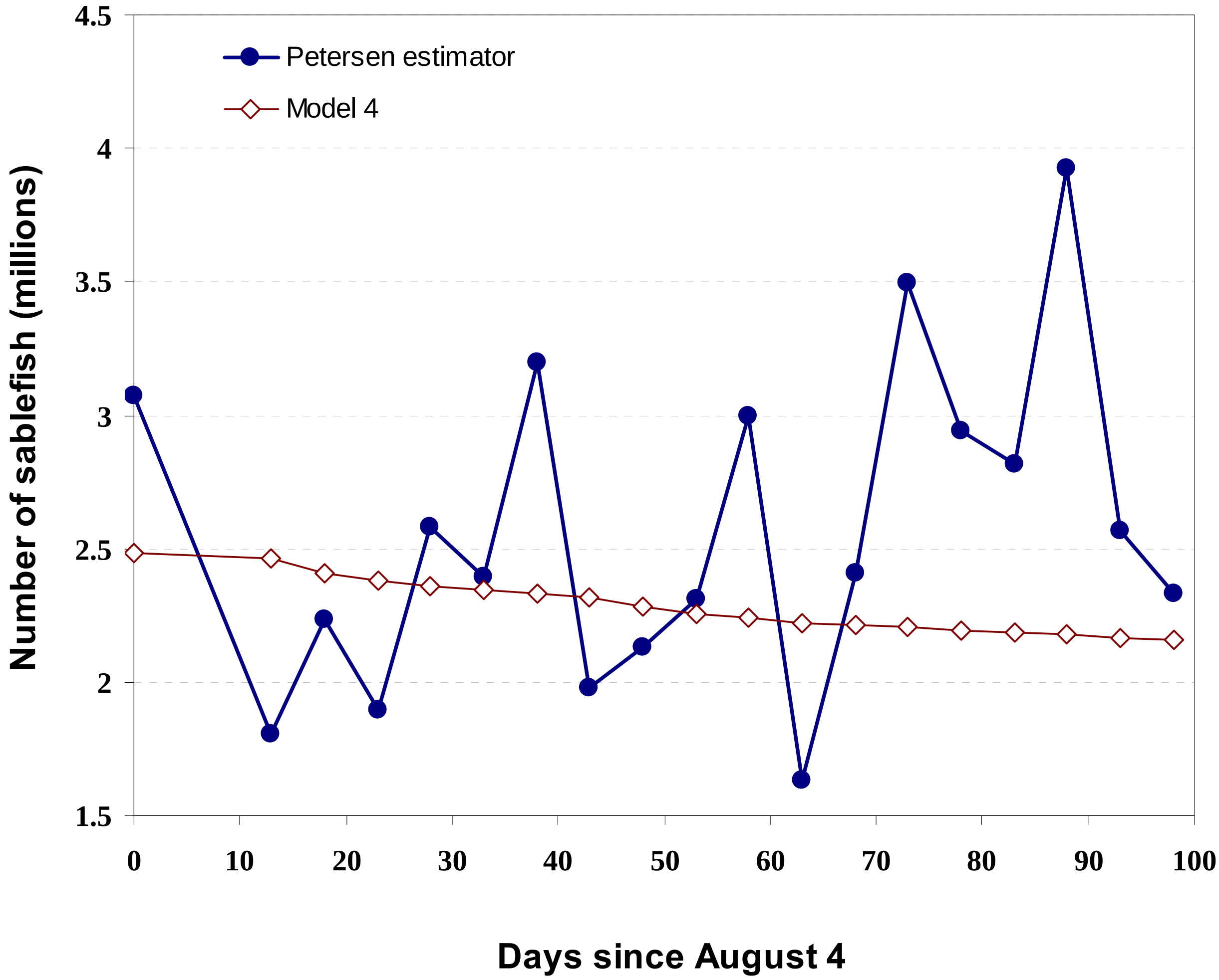
Appendix C10.–Model 3 estimates of sablefish abundance and corresponding time-stratified Petersen estimates of abundance for longline survey and 18 consecutive 5-day fishery periods. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



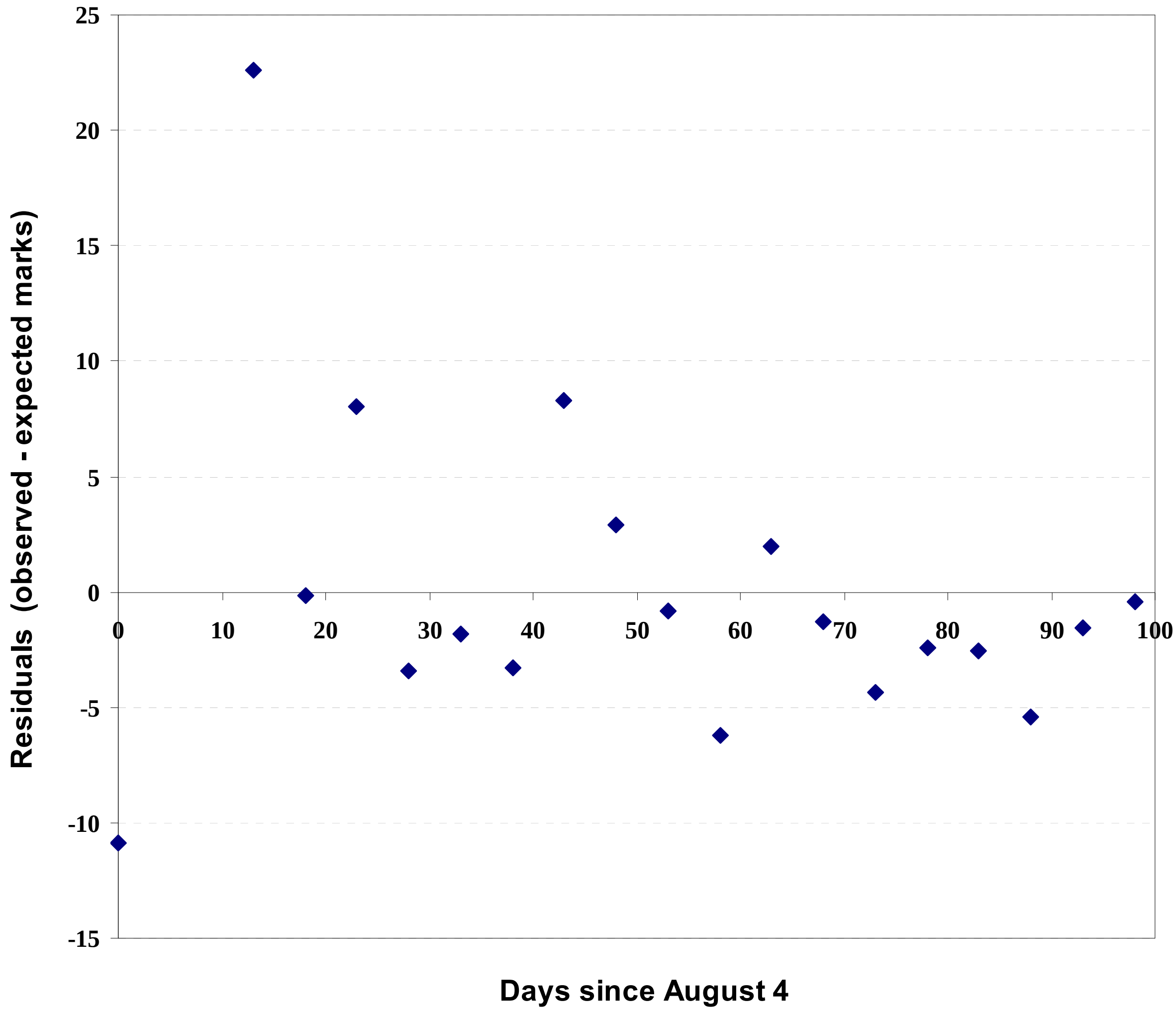
Appendix C11.–Model 4 estimated trend in fishery CPUE and observed fishery CPUEs for 18 consecutive 5-day fishery periods. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



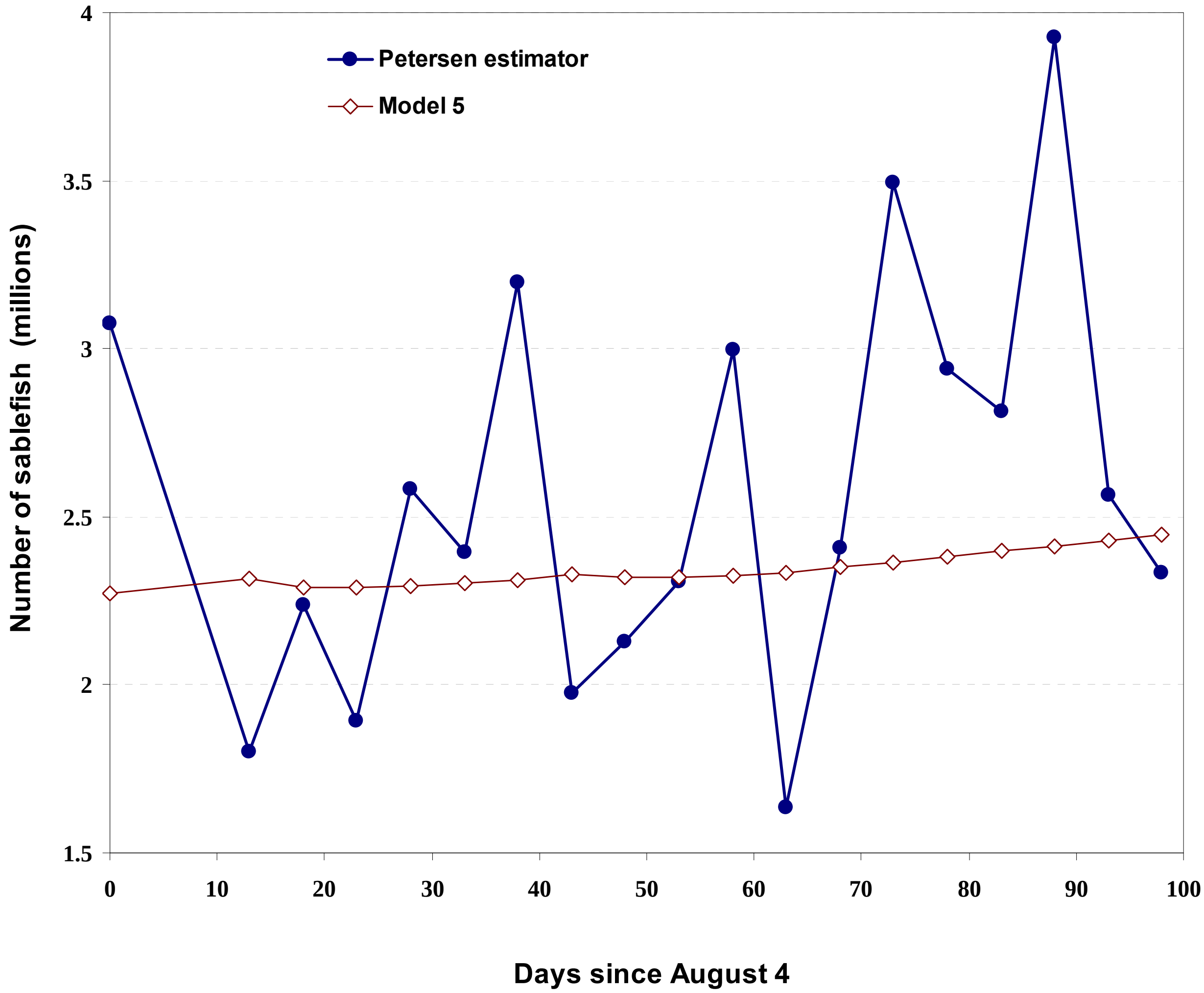
Appendix C12.–Trend in observed minus expected number of marks by sampling period (LL survey and 18 fishery periods) based on Model 4. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



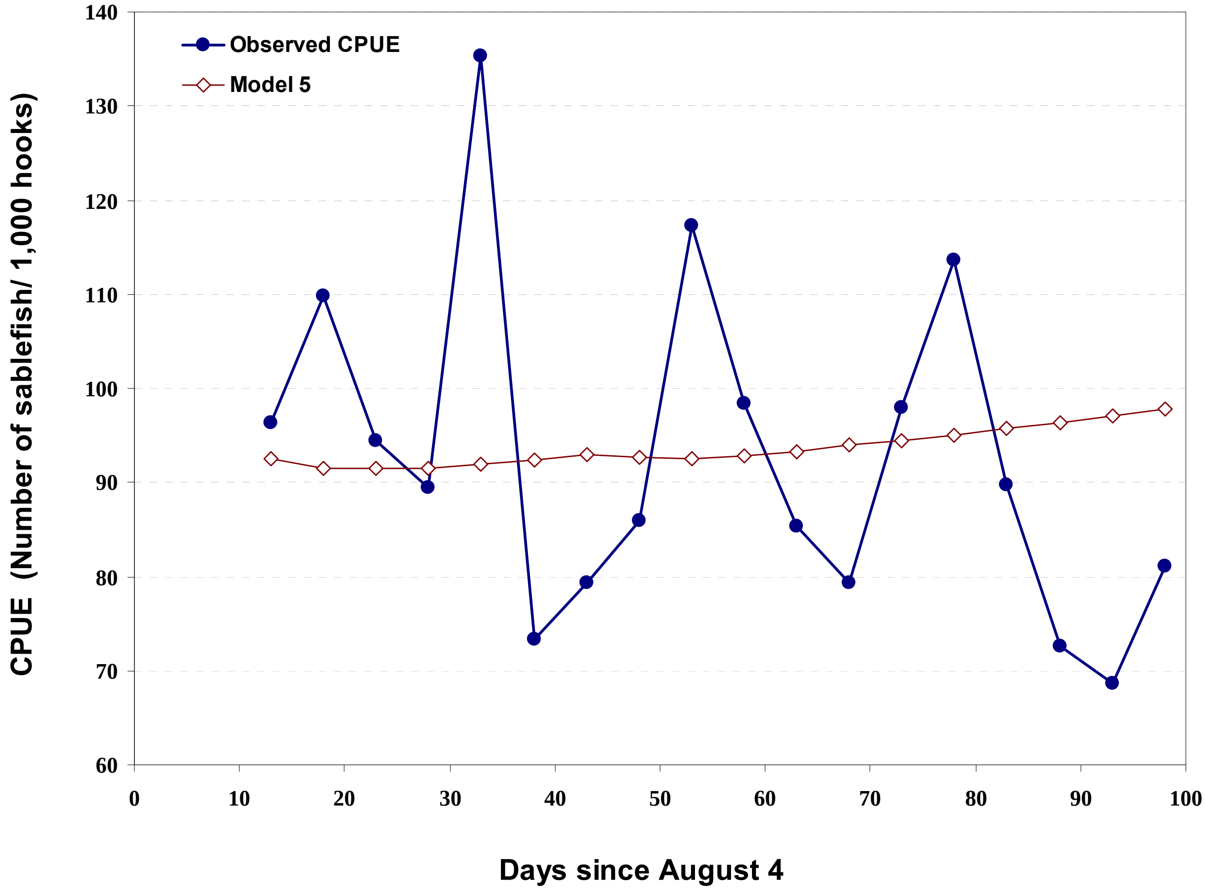
Appendix C13.–Model 4 estimated trend in sablefish abundance over time and corresponding time-stratified Petersen estimates of abundance for longline survey and 18 consecutive 5-day fishery periods. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



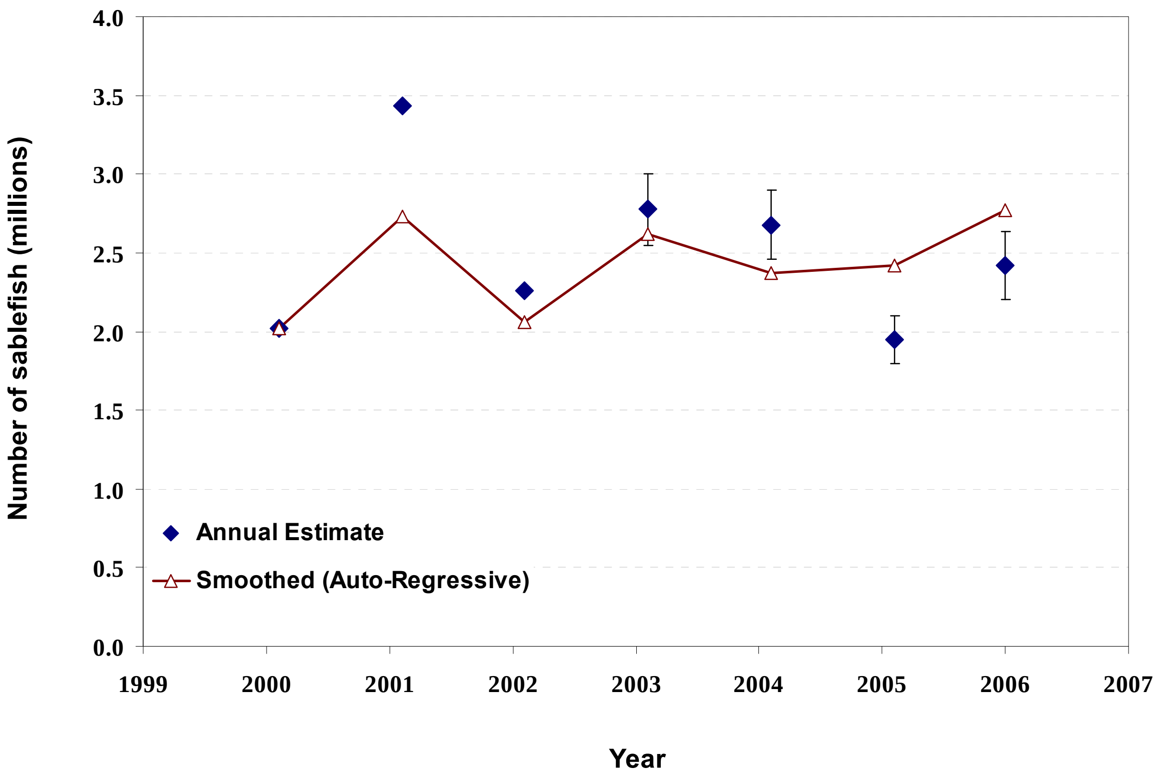
Appendix C14.–Trend in observed minus expected number of marks by sampling period (LL survey and 18 fishery periods) based on Model 5. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



Appendix C15.–Model 5 estimated trend in sablefish abundance over time and corresponding time-stratified Petersen estimates of abundance for longline survey and 18 consecutive 5-day fishery periods. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



Appendix C16.–Model 5 estimated trend in fishery CPUE and observed fishery CPUEs for 18 consecutive 5-day fishery periods. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.



Appendix C17.–Historical estimates of numerical abundance of sablefish in Chatham Strait, 2000–2006. Estimates in 2000 and 2002 were converted from biomass estimates based on exploitation rates to total numerical abundance using average individual weights from the fishery. Line connects smoothed estimates based on a first-order autoregressive model of order 1. This appendix is part of Franz Mueter's NSEI sablefish stock assessment analysis, developed while under contract with the Alaska Department of Fish and Game.